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Using precision agriculture field data to evaluate combine harvesting efficiency

Justin H. Carroll
University of Arkansas, Fayetteville

Don Johnson
University of Arkansas, Fayetteville

Jeff Miller
University of Arkansas, Fayetteville

Kristofor Brye
University of Arkansas, Fayetteville

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Justin H. Carroll*, Don Johnson[†], Jeff Miller[§], and Kristofor Brye[‡]

Abstract

Soybeans 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 9 meter 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% (mean = 80.9%, standard deviation (SD) = 9.6%); width efficiencies (WE) ranged from 96.7% to 98.8% (mean = 97.6%, SD = 1.6%); and overall field efficiencies (FE) ranged from 70.4% to 84.8% (mean = 79.0%, SD = 9.7%). Contrary to expectations, neither row length nor unadjusted yield was significantly correlated ($P < 0.05$) 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 that the use of geo-referenced field and performance data can be helpful in evaluating combine performance and efficiency.

*   Justin H. Carroll is a December 2015 Honors Program graduate with a major in Agricultural Systems Technology Management and a minor in Agricultural Business.

[†]   Don Johnson is the faculty mentor and a professor in the Department of Agricultural Education, Communication, and Technology.

[§]   Jeff Miller is a professor in the Department of Agricultural Education, Communication, and Technology.

[‡]   Kristofor Brye is a professor in the Department of Crop, Soil, and Environmental Sciences.

Meet the Student-Author

I am from Brinkley, Arkansas and graduated from Brinkley High School in 2012. In 2015, I graduated from the University of Arkansas with a Bachelor of Science degree in Agricultural Education, Communication, and Technology. This spring, I began pursuing a Masters Degree in Agricultural and Extension Education.

During my undergraduate career, I was a member of the Razorback chapter of Collegiate Farm Bureau, the Xi chapter of Kappa Sigma, and Ducks Unlimited. Through my honors thesis research, I gained valuable research experience and learned the importance of student-mentor communication in accomplishing large tasks.

I would like to thank Don Johnson for supporting me and providing me with his guidance while I completed my honors research. I would also like to thank Jeff Miller and Kristofor Brye for providing valuable input, advice, and serving on my committee. I am also honored to have received funding for this research from the Dale Bumpers College of Agricultural, Food, and Life Sciences.

Justin Carroll

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 help 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 in 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 efficiency (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 (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 et al. (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, time efficiency, 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.

Key Terms

- Advanced Farming Systems (AFS) are factory installed machine technology capable of recording yield and spatial data and monitoring machine conditions.
- Field efficiency is 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).
- Row length is the effective length, in meters, that the combine traveled in one pass through the field.
- Crop yield is the amount of crop harvested over a given area. Kilograms per hectare is the unit of measurement used.
- FarmLogic is farm record keeping software.

Materials and Methods

The field efficiency of a 2012 CaseIH 8120 Axial-Flow combine (Fig. 1) harvesting with a 9-meter MacDon D-65 Draper header was tested. Since one of the independent variables was crop yield, the onboard AFS was used, equipped with an AFS Pro 600 Model display and an AFS 262 GPS receiver (Fig. 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, Tennes-

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

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

see with 15-30 cm accuracy. To achieve accuracy in yield readings, a field technology consultant for Eldridge Supply in Brinkley, Arkansas, 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. The accuracy of the AFS was checked by comparing AFS readings to moisture of the previously cut samples and checking that sample for the 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.

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.

The three fields (Fig. 3) selected for data collection were located southeast of Brinkley, Arkansas and northwest of Moro, Arkansas. 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 49 ha (hectares) to approximately 91 ha and were relatively rectangular in shape. Each field was divided into four approximately sized replicates post-harvest using ArcGIS software.

Fields of different lengths, ranging from approximately 280 m to 420 m, 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. Soybean was planted on 60-inch beds with 15-inch spacing between each row of soybean and three rows per bed.

Fig. 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.

Several assumptions were made during the study in order to adhere to reasonable harvest dates. The 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 involving driving technique were consistent. Also, even though the fields were not all planted on exactly the same date, it was assumed that all three fields had optimal periods for the crop to grow.

Once the data were collected, a FieldPro for Greenway Equipment in Brinkley, Arkansas, 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 correlation. 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).

Results and Discussion

Descriptive statistics for plot size, row length, grain moisture, unadjusted and adjusted yields are presented, by field, in Table 1. Mean row lengths for the three fields ranged from 277 m to 423 m and mean unadjusted yields ranged from 3416.2 kg/ha to 4281.8 kg/ha. Adjusted to standard 13% moisture content, mean yields ranged from 3648.3 kg/ha to 4371.9 kg/ha.

Table 2 provides summary statistics for various combine performance measures by field. Mean field speeds ranged from 4.0 to 6.0 km/h with an overall mean field speed of 4.8 km/h. 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 84.8% (Field 1) for an overall FE of 79%.

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 correlation was not considered important because higher moisture means higher weight of crop and the combine reads yield by weight of crop.

The results indicated TE was the most important predictor, explaining 90.5% (sr^2 = 0.9046) of the unique variance in FE; WE explained only 1.6% (sr^2 = 0.0163) of the variance in FE when controlling for TE. Both coefficients were statistically significant (P < 0.0001). No significant relationship occurred between row length, unadjusted yield, WE, and FE in the study.

Table 1. Means and standard deviations (SD) for field and yield variables by field (n = 4).

	Field					
	No. 1 (14.91 ha)		No. 2 (15.86 ha)		No. 3 (8.15 ha)	
Variable	Mean	SD	Mean	SD	Mean	SD
Plot size (hectares)	3.72	0.37	3.96	1.16	2.04	1.35
Row length (m.)	423.98	4.50	277.67	96.74	347.47	0.00
Grain moisture (%)	11.41	0.20	8.90	0.07	9.74	0.11
Unadjusted yield (kg/ha)	4281.77	1.39	3416.27	1.30	3784.8	1.03
Adjusted yield (at 13% moisture content)	4371.89	1.42	3648.29	1.36	3942.84	1.07

Table 2. Means and standard deviations (SD) for combine field performance variables by field number (n = 4).

	Field					
	No. 1 (14.91 ha)		No. 2 (15.86 ha)		No. 3 (8.15 ha)	
Variable	Mean	SD	Mean	SD	Mean	SD
Field speed (km/h)	5.94	0.35	4.80	0.09	3.99	0.33
Working width (m)	9.04	0.23	8.91	0.10	8.84	0.68
Width efficiency (%)	98.85	0.76	97.40	0.00	97.70	0.02
Productive time (min)	35.78	1.24	46.72	4.52	25.52	8.12
Total time (min)	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.

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. TE = time efficiency, WE = width efficiency, FE = field efficiency.

The study's results led to several conclusions regarding WE, TE, and FE. Width efficiency was found to be consistent and high (>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 caused little variation in FE ($r = 0.31$) in the planter seeded cropping system used in this study.

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 FEs range from 70.4% to 84.9%, which is equal to or higher than typical FE, which ranges from 65% to 80% (ASAE, 2011). Time efficiency primarily limited FE because TE was the main factor in calculating FE in the study. Time efficiency alone explained 90.5% of the unique variance in FE, while WE only explained 1.6% of the unique variance in FE. 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 achieving typical FE. Shamshiri et al. (2012) calls these factors "non-productive" time and they include turning time at row-ends, driver breaks, equipment adjustment, and machine cleaning. 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.

The study's findings related to row length and yield differ from the findings of Grisso et al. (2002). Where Grisso et al. 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 findings related to yield. In their study, Grisso et al. (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.

Extraction and conversion of machine data was one of the difficulties involved in this study, specifically, the compatibility of data and data processing programs. Not all programs can process data from any precision agriculture provider. This study recommends that precision agriculture vendors work to provide more readily available and user-friendly data for farmers, so that they can easily use it to make more informed machinery management decisions.

Based on the high overall high WE in the study, it is recommended that farmers align their header width used in harvesting with their row and bed spacing used while planting. Overall this study concluded that time losses should be limited while harvesting in order to increase TE, which in turn increases overall FE. Therefore, precision agriculture data collected while harvesting can be used to evaluate performance and is a basis for making more informed machinery management decisions.

Acknowledgements

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