This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 32, No. 2, pp. 409-413, 1989)
Published by the American Society of Agricultural Engineers, St. Joseph, MI 49085-9659 USA

Yield Determination Using a Pivoted Auger Flow Sensor

L. E. Wagner, M. D. Schrock
STUDENT MEMBER ASAE ASSOC. MEMBER ASAE

ABSTRACT

A pivoted auger grain flow sensor, installed on a commercial combine, was evaluated as a means of determining yield variations within a field while harvesting wheat and grain sorghum. Digital filtering techniques were used to deal with signal noise. Grain yields from field plots could be determined within ±3% of the actual harvested yields while still detecting yield variations within plots. Vibration, vehicle motion, grain transportation time lag through the combine and unsteady flow rates also were investigated.

INTRODUCTION

In recent years, much effort has been focused on the control of crop production practices to match the individual needs of specific areas of a field. One technique is to measure the independent variables prior to an application operation and develop a "control map" which is then transferred to the application vehicle (Schmitt et al., 1986). A map of a previous crop's grain yield could be used in developing that control map.

Yield maps could also be used for accurate evaluation of individual prescription farming methods and as a useful feedback tool for grain producers. For example, a yield map might illuminate previously unknown problems with fertility, drainage or disease. A yield map may also encourage experimentation by the producer since crop varieties, fertility treatments, planting rates, or tillage methods could easily be compared on a yield basis.

The key elements of a grain yield mapping system are a grain flow sensor, a navigation unit for determining machine position and a computer for performing calculations and results. This report covers initial field trial results using a pivoted auger grain flow sensor for determining yield variations within a field while harvesting crops with a commercial combine. The sensor concept was designed and tested in the laboratory (Wagner and Schrock, 1986, 1987). Three primary objectives of the field tests were:

1. To determine the accuracy of the grain flow sensor under field conditions.
2. To determine the time lag that exists between the cutting of the crop at the header and the entry of grain into the combine grain tank.
3. To propose and implement modifications to improve the flow sensor's performance in the field.

GRAIN FLOW SENSOR AND INSTRUMENTATION

The pivoted auger grain flow sensor was installed above the grain tank of a Deutz-Allis N6 Gleaner combine*. The combine's original bin filling auger was modified to discharge grain into the pivoted auger. The pivoted auger was driven hydraulically, with speed controlled by a flow control valve mounted within reach of the operator. A 700 kg capacity catch bin was suspended from three load cells beneath the discharge end of the flow sensor for mas grain flow rate verification. Figure 1 shows the configuration of the pivoted auger grain flow sensor mounted on the combine. The combine bin was unloaded into a 3000 kg portable scale for verification of yields.

A Zenith Z-158 microcomputer equipped with a Tecmar LabMaster data acquisition system was installed in the cab of the combine and powered from the combine's electrical system through an inverter. The following signals were sampled with this system:

1. Pivoted auger rotation speed using a magnetic pickup sensor.

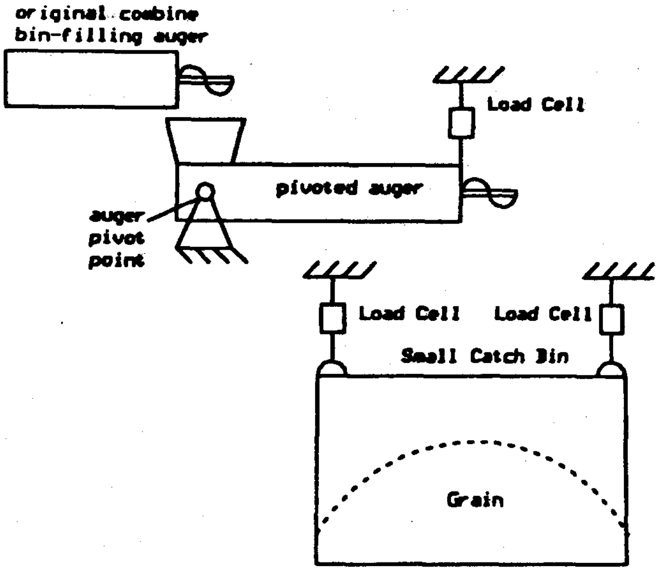

Fig. 1—Schematic of pivoted auger setup.

Article was submitted for publication in November, 1988; reviewed and approved for publication by the Power and Machinery Div. of ASAE in February, 1989. Presented as ASAE Paper No. 87-1516.

This research was supported by the Kansas Agricultural Experiment Station (Contribution No. 89-69-J), the Kansas Advanced Technology Commission, and supplmented by equipment loan from Deutz-Allis Corporation.

The authors are: L. E. WAGNER, Agricultural Engineer, USDA-Agricultural Research Service, Wind Erosion Research Unit, Kansas State University, Manhattan; and M. D. SCHROCK, Associate Professor, Agricultural Engineering Dept., Kansas State University, Manhattan.

*The use of trade names in this publication does not imply endorsement of the products named.

2. Pivoted auger weight using a 450 N capacity load cell installed at the discharge end of the pivoted auger.
3. Pivoted auger vertical acceleration from an accelerometer mounted on the discharge end of the auger.
4. Vertical acceleration of combine from an accelerometer mounted on the pivoted auger support frame.
5. Combine travel speed using an existing magnetic pickup sensor on the combine drive line.
6. The cumulative mass of grain discharged from the grain flow sensor held in the 700 kg catch bin using three load cells (26.4 kN total capacity).

A complete description of the hardware configuration of the data acquisition system used during the field tests along with the source listings for the software used is included in Wagner (1988).

DATA COLLECTION PROCEDURES AND ANAYSIS

Wheat Harvest Field Tests

Field data were obtained while harvesting wheat at two locations in southcentral and northcentral Kansas. During these tests, data were collected every 10 ms, and the grain flow sensor data were pre-processed each second according to an averaging technique developed during laboratory testing (Wagner and Schrock, 1986). The one-second averaged data then were recorded on the microcomputer's hard disk for later analysis.

Small test plots were constructed in several fields at both locations for tests undertaken during wheat harvest. The plots were harvested in two manners: (1) using constant travel speeds to maintain a relatively constant grain flow rate into the combine, or (2) introducing a change in travel speed while harvesting the plot to obtain a change in grain flow rate.

Typical constant travel speed data are shown in Fig. 2. The times the combine header entered and left the plot were recorded during data collection. The times when grain flow measurement began and ended were determined from the raw data. All of these times are represented in Fig. 2 by the vertical dashed lines.

Modifications to Data Collection Procedures

Suitable information on the sensitivity of the grain flow sensor was not obtained with the one-second averaged data from the wheat harvest trials, primarily because of the amount of fluctuation still remaining in the data after the pre-processing of the auger weight readings. The averaging method, which worked well during the controlled laboratory tests (Wagner and Schrock, 1987) was designed to only cancel frequencies and harmonics related to the actual auger speed so noise from other sources on the combine, which generated different frequency ranges, was still present.

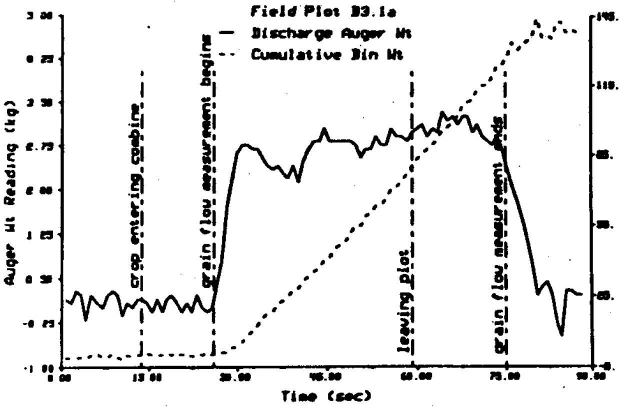

Fig. 2—Typical data from wheat harvest tests.

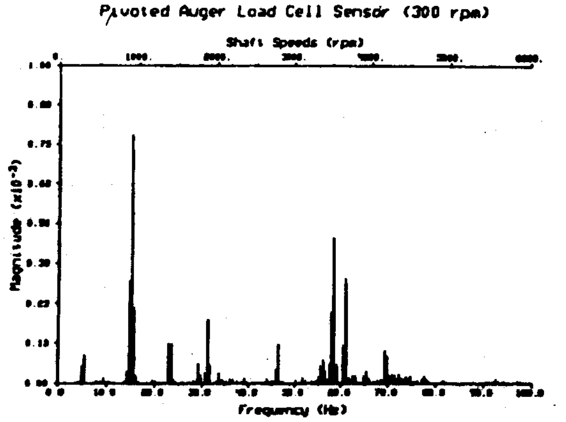

Fig. 3—Fourier transformation of typical sensor data.

Therefore, other techniques were studied following the wheat harvest tests. Visual inspection during the wheat harvest tests revealed that the discharge end of the pivoted auger would vibrate horizontally while running. Since this was a possible source of sensor noise, a small radius rod was installed to restrain the horizontal motion of the discharge end of the pivoted auger.

Next, sensor data were collected in the lab with the engine running at idle and operating speeds with and without the separator engaged. These data were collected at 2 ms time intervals. A Fourier transformation then was performed on the data to determine the predominant frequencies. The results of the Fourier analysis revealed that frequencies associated with combine cylinder, engine speed and other shafts were more prevalent than those from the pivoted auger rpm (Fig. 3). The cylinder speed was approximately 900 rpm and engine speed was 2000 rpm. These tests were performed with and without the radius rod installed, but no conclusive results could be drawn from this information in the lab setting.

Because of our experiences with the field tests during wheat harvest, the data collection method was modified for the grain sorghum field tests. A user-specified number of samples (limited by computer memory to about 15,000 data points) was collected and stored on disk in binary format without data pre-processing. After a set of constant-time-interval data was written to disk, sampling of another set of data would immediately begin. This provided us with several sets of constant-time interval data for each plot harvested. The recording of raw, unprocessed data vastly increased the amount of data to be handled but allowed off-line experimentation with various data reduction techniques.

Grain Sorghum Harvest Field Tests

Field tests were conducted while harvesting grain sorghum in the fall in northeast Kansas. The field was divided into small plots to repeat the type of testing performed while harvesting wheat during the summer.

The specific yields varied greatly among the plots

TABLE 1. Actual and Predicted Yields for Grain Sorghum Harvest Plots

Plot site	Plot area (m^2)	Specific yield (kg/ha)	Scale yield (kg)	Bin yield (kg)	Sensor yield (kg)	Bin error (%)	Sensor error (%)
a1	–	1225	–	509.0*	551.9	–	8.43‡
a2	1107	4097	453.6	445.9	445.4	–1.70	–0.11
a3	1107	4158	460.4	450.5	459.4	–2.15	1.97
a4	1107	3913	433.2	431.8	437.3	–0.32	1.27
a5	1107	3913	433.2	426.6	421.6	–1.52	–1.16
a6	997	2730	272.2	287.0	290.9	5.44	1.37
b1	1385	1506	208.7	203.0	178.3	–2.73	–12.17§
b2	1385	2652	367.4	350.0†	349.0	–4.75†	–0.29
b3	1385	3045	421.8	413.1	413.4	–2.06	0.08
b4	1385	3635	503.5	499.5	499.8	–0.79	0.06
b5	1385	3815	528.4	532.7	536.2	0.81	0.65
b6	1247	2400	299.4	278.0*	276.0	–7.15*	–0.74
c1	883	4032	356.1	357.0	341.1	0.25	–4.45
c2	883	4186	369.7	363.2	360.2	–1.76	–0.82
c3	883	3980	351.5	339.3	334.1	–3.47	–1.53
c4	883	3955	349.3	341.4	337.5	–2.26	–1.13
c5	883	3492	308.4	297.7	298.4	–3.47	0.22
c6	795	2054	163.3	154.1	154.9	–5.63	0.54
d1	1268	4364	553.4	566.5*	579.2	2.37*	2.24
d2	1036	4312	446.8	438.0	426.9	–1.97	–2.54
d3	1036	4553	471.7	461.8	451.1	–2.10	–2.33
d4	1036	4860	503.5	500.9	497.6	–0.52	–0.65
d5	1036	5231	542.0	531.2*	520.0	–2.00	–2.10
d6	932	3917	365.1	360.0	350.6	–1.40	–2.62

* Data collection terminated prematurely and/or the small catch bin overflowed

† Ending bin weight data garbled on storage media

‡ Plot with the largest average auger flow rate

§ Plot with the lowest average auger flow rate

(Table 1). This variability existed primarily because of a lack of soil moisture during the growing season and poor weed control along field boundaries. The yield variability observed among these plots provide an indication of the degree of variation that can exist in a field. The maximum plot yield was nearly 3.5 times the minimum plot yield (Table 1), with an average yield of 3687 kg/ha and standard deviation of 903.7 kg/ha.

The raw pivoted auger flow sensor data were processed through a digitally implemented 4-pole Butterworth lowpass filter. The theory, design and implementation of the filter used is contained in Wagner (1988). Experimentation with various cutoff frequencies for the lowpass filter was performed to study it's transient response to changes in the actual data stream. It was determined that a 1/2 Hz cutoff frequency had an appropriate transient response to changes in the actual flow sensor data and still suppressed the low frequency (2.5 Hz) noise related to the pivoted auger's rotation speed of 150 rpm. Sets of raw and filtered data are shown for a typical plot site in Figs. 4 and 5, respectively.

RESULTS AND DISCUSSION

Grain Flow Time Lag Through The Combine

The time delay between the start of crop intake at the header and when actual grain flow measurement occurs can be represented theoretically as a *transportation delay* (time for grain to physically travel from the header to the grain tank) and a *1st-order time lag* (accounts for the redistribution of material inside the combine). Bae (1987) used this model to represent the combine's response to a step input of crop at the header. He found the transportation delay to be a function of grain flow rate with higher grain flow rates exhibiting lower transporation delays.

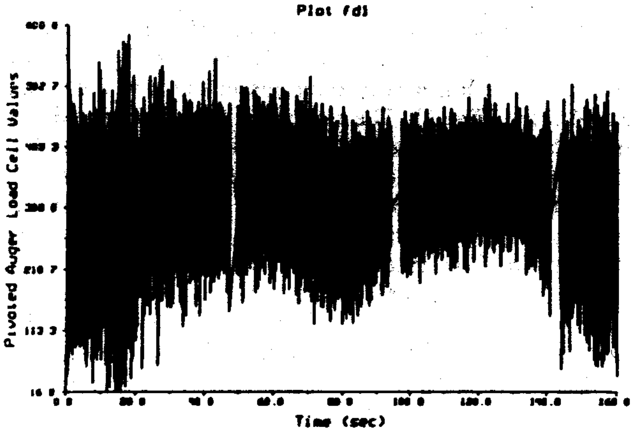

Fig. 4—Actual plot site data.

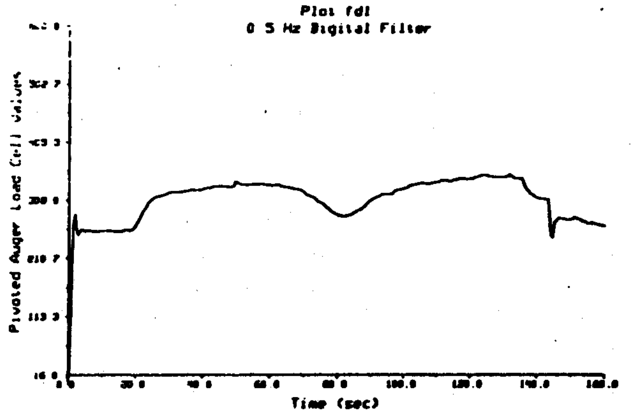

Fig. 5—Digitally filtered plot site data.

Crop entry and exit transportation delay times were obtained while harvesting the wheat plots. Results from several field locations shown in Table 2 reveal a 14 to 15 s time lag for both cases. An attempt to measure the time lag between header input and actual grain flow rate measurement when a change in feedrate occurred while harvesting the crop proved less conclusive (Table 2), as evidenced by the large standard deviation of times measured. No attempt was made to determine the 1st-order time lag from the data.

Grain Flow Sensor Calibration (Wheat Harvest)

Plots harvested at a constant travel speed were selected on the basis of visual uniformity. If the plots were uniform, they should have provided a nearly constant mass flow rate of grain into the small catch bin. The small catch bin calibration was periodically checked witha portable yield scale.

TABLE 2. Grain Flow Measurement Time Lag

	Entering Crop			Leaving Crop			Within Crop		
Field Site	No. plots	Time (sec)	Std. Dev (sec)	No. plots	Time (sec)	Std. Dev (sec)	No. plots	Time (sec)	Std. Dev (sec)
1	24	15.32	1.61	24	14.11	2.20			
2	9	14.84	0.94	8	14.74	1.45			
3	9	14.21	0.59	10	13.71	1.62			
4	14	14.32	1.57	14	14.93	1.42			
5.1	26	13.17	1.30	22	15.34	1.62			
6	8	13.21	0.85	8	14.61	1.42	6	21.3	6.87
all	90	14.20	1.56	86	14.62	1.79	6	21.3	6.87

The beginning and ending boundaries for constant mass flow for each plot were determined by visually examining the bin weight readings in the raw data (see dashed lines, Fig. 2). The slope of a linear regression of the catch bin weight readings was used to determine the actual mass flow rate of grain harvested for each plot.

The laboratory work suggested that a 2nd-order polynominal related the grain flow sensor output to the actual grain flow rate (Wagner and Schrock, 1987). However, the field data were collected over a much smaller range of actual grain flow rates than the laboratory data. Thus, a simple linear regression provided essentially the same degree of fit to the calibration data as a polynomial curve. This linear regression achieved an adjusted R^2 value of 0.9873 using data from 26 test plots. The actual calibration curve was:

$$\begin{matrix}\text{mass}\\ \text{grain}\\ \text{flow}\end{matrix}\left[\frac{\text{kg}}{\text{s}}\right] = 0.006818\left\{\begin{matrix}\text{auger}\\ \text{speed}\end{matrix}\left[\frac{\text{rev}}{\text{min}}\right] * \begin{matrix}\text{auger}\\ \text{wt}\end{matrix}\left[\text{kg}\right]\right\} \qquad [1]$$

A plot of the actual grain flow rate determined from the small bin weight readings and the product of the pivoted auger weight and rpm readings is shown in Fig. 6.

By integrating the calibrated pivoted auger flow sensor readings over time for each of the plots, the absolute sensor accuracy can be estimated. The resulting plot yields determined from the small catch bin and the flow sensor are provided in Table 3. In most cases, yields derived from the flow sensor readings fell within ±10% of the actual plot yields.

Grain Flow Sensor Calibration (Grain Sorghum Harvest)

Sensor accuracy was evaluated in the following manner using the grain sorghum harvest field data:

1. A moving linear regression using 10 data points was performed on the bin weight values to determine the actual grain flow rate (slope of bin weight values over time) and calibrate the pivoted auger grain flow sensor. The average auger weight and rpm values over the same time intervals used by the moving regression were also obtained. if fewer than 10 points were used in the regression, the correlation between the change in the bin weight readings and the grain flow rate sensor deteriorated significantly. The filtered data time interval was approximately 0.2 s, so about 2 s of data were used in the moving regression.
2. All moving regression bin weight data points that indicated a grain flow rate greater than 11 kg/s, or nearly double the maximum actual grain flow rate, were discarded as well as any values less than zero.
3. A linear regression between the actual grain flow determined from the moving regression of the small catch bin weight readings and the product of the pivoted auger weight and rpm readings determined the pivoted auger grain flow sensor's calibration equation. The linear regression achieved an adjusted R^2 value of 0.8931 using data from the 24 test plots. The actual calibration curve was:

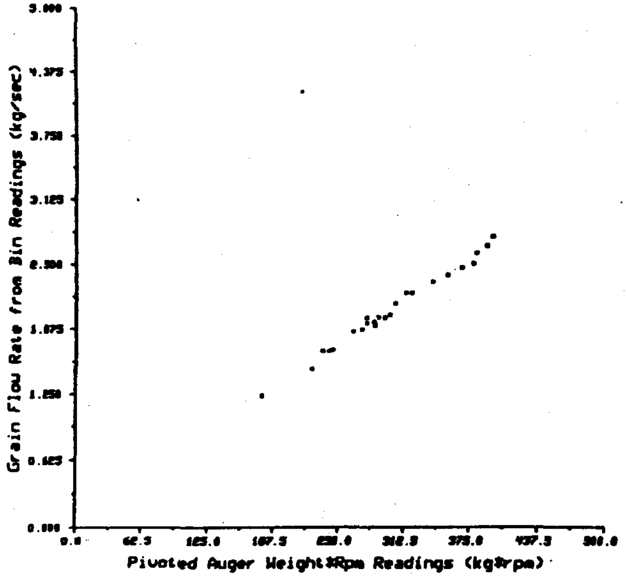

Fig. 6—Scatter plot of calibration data from wheat plots.

TABLE 3. Actual and Predicted Yields for Wheat Harvest Plots

Plot site	Plot area (m^2)	Specific yield (kg/ha)	Bin yield (kg)	Sensor yield (kg)	Sensor error (%)
a	436	3171	138.4	139.0	0.43
b	431	3436	148.1	152.4	2.90
c	433	3223	139.5	142.4	2.08
d	431	3376	145.5	146.6	0.76
e	433	3242	140.3	145.5	3.71
f	433	3212	139.0	143.9	3.53
g	436	3157	137.8	141.8	2.90
h	433	3364	145.6	146.0	0.27
i	431	2988	128.8	131.0	1.71
j	433	3165	137.0	135.9	−0.80
k	435	2991	130.0	130.0	0.00
l	440	2749	121.0	122.1	0.91
m	442	2659	117.5	115.3	−1.87
n	442	2097	92.7	91.6	−1.17
o	440	2574	113.3	103.6	−8.56
p	444	2754	122.2	120.6	−1.31
q	448	2725	122.1	121.8	−0.25
r	446	2544	113.5	107.4	−5.37
s	448	2616	117.2	126.4	7.85
t	444	1546	68.6	69.5	1.31
u	446	2709	120.9	119.9	−0.83
v	444	2672	118.6	118.5	−0.08
w	444	2352	104.4	104.4	0.00
x	444	2790	123.8	124.1	0.24
y	448	2723	122.0	107.9	−11.56
z	444	2902	128.8	126.2	−2.02

$$\begin{matrix}\text{mass}\\ \text{grain}\\ \text{flow}\end{matrix}\left[\frac{\text{kg}}{\text{s}}\right] = 0.006347\left\{\begin{matrix}\text{auger}\\ \text{speed}\end{matrix}\left[\frac{\text{rev}}{\text{min}}\right] * \begin{matrix}\text{auger}\\ \text{wt}\end{matrix}\left[\text{kg}\right]\right\} \qquad [2]$$

A plot of the actual grain flow rate determined from the small bin weight readings with the moving regression and the product of the pivoted auger weight and rpm readings is shown in Fig. 7. Absolute sensor accuracy was then determined by integrating the calibrated pivoted auger flow sensor readings over time for each of the plots. Plot yields determined from the small catch bin

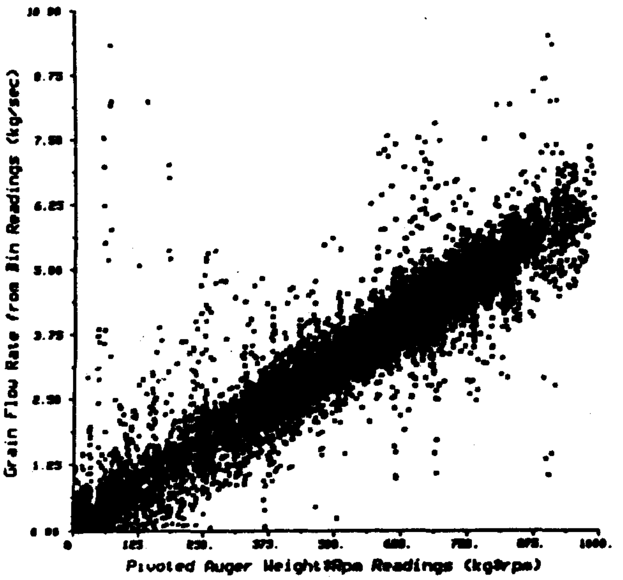

Fig. 7—Scatter plot of calibration data from grain sorghum plots.

and the flow sensor are provided in Table 1. The small catch bin and portable scale weights for each plot are also provided in Table 1 along with the percent error between the two measurements. Except for the plots harvested at the greatest and least average mass flow rates, all plot yields derived from the flow sensor readings fell within ±3% of the actual yields.

CONCLUSIONS

1. Filtering the sensor data through a lowpass filter appears to be a viable method to significantly reduce the high frequency noise that is present on the flow sensor output. The majority of the noise present can be traced back to the cylinder, engine and other rotating shafts on the combine.
2. Use of the lowpass filter allowed the pivoted auger grain flow sensor to obtain plot yields within ±3% of the actual yields.
3. The sensitivity of the pivoted auger grain flow sensor is sufficient to detect changes in grain flow rate (yield) within the small plots as shown in Fig. 5.
4. The field test results indicate that a pivoted auger grain flow sensor has potential as a tool to determine yield variations while harvesting a crop.

References

1. Bae, Y. H. 1987. Mapping grain yield with a combine instrumented for location detection. Unpublished diss. Texas A&M University, College Station.

2. Schmitt, M. A., W. G. Walker and D. Fairchild. 1986. Computer fertilizer application by soil type. p. 1-5. In *Proc. of 1986 Great Plains Fertility Workshop.*

3. Wagner, L. E. and M. D. Schrock. 1986. Grain flow measurement with a pivoted auger. ASAE Paper No. 86-1581.

4. ________________. 1987. Grain flow measurement with a pivoted auger. *Transactions of the ASAE* 30(6):1583-1586.

5. Wagner, L. E. 1988. Development of an auger-based grain flow meter for use in a yield mapping system. Unpublished diss. Kansas State University, Manhattan.