Design and evaluation of a yield monitoring system for combinable crops

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Abstract: The existence of spatial variability within fields can be beneficial if inputs for arable crop are given to the field according to locally determined requirements. While yield mapping has become an important part of precision farming strategies, the goal of this paper is to plot a yield map by the application of yield monitoring components. A yield monitoring system capable of providing sufficient reliable data to plot a yield map for small grain fields in central regions of Iran was developed. The system consisted of an impact flow sensor determining the mass flow of grain, the GPS receiver determining geographical position of the machine, two shaft encoders measuring the speed of the combine, an ultrasonic sensor measuring the actual cutting width, and a data logger. The mass flow sensor consisted of a load cell and an impact plate which was exposed to the predominant grain flow from the clean grain elevator. This sensor was positioned in the transition housing between the elevator and the loading auger of the clean grain tank. The calibration of the sensor related the force on the sensor to the mass flow rate of grain. The yield data were used with information generated by the GPS receiver and a yield map was created. At last, the correlation between the maps and the data collected using traditional method was found which supports the reliability of the monitoring system.

Keywords: wheat, spatial variability, yield map, mass flow sensor, precision farming

Citation: Kargarpour, H., J. Razavi, A. Hemmat., and M. R. Salar. 2016. Design and evaluation of a yield monitoring system for combinable crops. Agricultural Engineering International: CIGR Journal, 18(3):84-93.

1 Introduction

Precision agriculture and more precisely, site-specific management (SSM) tries to address variability within the field instead of treating the whole field as one homogeneous management unit. One of the most important objectives from the stand point of farmers is the optimization of profit for each and every field. With the ever increasing population, the demand for food has also increased exponentially which in turn has led to the increased use of fertilizer to meet up the requirements. However, besides ecological concerns and the cost increased amount of fertilizers can cause serious health issue as well as effects the plant growth. This has gained attention of researchers worldwide to find effective ways to optimize plant yield while minimizing the application and consumption of fertilizers (Laskar and Mukherjee, 2016). One approach is to minimize inputs application. This benefit directly corresponds to and affects yield and crop quality. Yield is usually thought of on a per hectare basis and is determined by dividing the total yield from a field (i.e. kilograms of lint, tons of grain, etc.) to area harvested (Plant, 2001). Miller et al. (1999) listed three criteria that must be satisfied in order for SSM to be justified which are, (1) that, significant within field spatial variability exists in factors that influenced crop yield, (2) that, causes of this variability can be identified and measured, and (3) that, the information from these measurements can be used to modify crop-management practices to increase profit or

Received date: 2015-12-10 **Accepted date:** 2016-06-18
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decrease environmental impact. Yield mapping is a technique by which the actual yield is measured across the entire field. By measuring the yield at each location within the field, a better picture can be obtained of the field's true variability. Yield monitor combined with GPS technology is an electronic tool that collects site specific data on crop performance on a given year. The underlying principle of yield mapping is the continual recording of the harvested crop mass, operating width and forward speed as the harvester moves across the field. The yield is calculated from these recorded parameters. Inexpensive sensors and microprocessors coupled with integrating software, mobile power sources, and satellite communications now enable farmers and natural resource managers to collect vast amounts of geo-referenced data (Auernhammer, 1994; Jahns, 2000). Further downstream processing of that data produces meaningful information and ultimately, knowledge (Udinkten Cate and Dijkhuizen, 1999). Research and development of precision farming sensors for combines started over two decades ago with the grain flow sensor. Whereas various sensors are marketed around the world, research is still ongoing to develop more accurate sensors. The most common form of output of yield monitor data is the familiar color-coded thematic yield map (Pierce et al., 1999). By far, the most well developed yield monitoring technology is that for combine harvested crops, especially, small grains. Borgelt (1993) provides a review of various types of grain-flow-rate monitor. Most modern systems measure mass-flow rate by measuring the force of grain impacting a plate located at the top of the clean grain elevator. Birrell et al. (1996) compared different methods and found that the impact-plate method most closely approximated a continuous sampling system. Whichever system is used, synthesis of the yield map must take into account of the errors inherent in the measurement process. Birrell et al. (1996) and Pierce et al. (1997) provide discussion and comparison of algorithms for correcting these various errors. Already, several methods of predicting yield have been developed such as; mass flow measurements by weighing of the grain bin (Colvin, 1990), weighing of pivoted auger (Wagner and Schrock, 1987), weighing of an element at the bottom cross auger (TSI Montana), weighing of an elevator (Schrock et al., 1995), volume flow measurements by means of optic sensors or light emitter and detector (Diekhans, 1985), paddle wheel (Searchy et al. (1989), and the most commercial ones, impact sensors (Vansichen and De Baerdemaeker,1991; Strubbe ,1997; Arslan and Colvin 1998). Other methods of yield measurements apply radiometric and capacitive detection systems. Nowadays, different commercial yield monitoring systems are being used all over the world that some of them are RDS Technology Ltd, the Claas quantimeter II, the Green star™ yield mapping system from John Deere Company, Advanced Farming Systems AFS™ from Case IH, the Deutz-Fahr Teris system, the GRAIN-TRAK yield measuring system by MICRO-TRAK, the Field Star® precision farming system of Massey Ferguson (AGCO), and Harvest Master. Inherent farm yield variability and agricultural inputs excessive application in many fields have resulted in lower productivity and contributed to higher production costs in various developing countries where farmers cannot afford high cost, modern production monitoring technologies. Yield map along with soil and water variability maps can be used to prescriptions for field in order to access better yield and performance (Bernardi et al., 2016; Thorp et al., 2015). Therefore, developing technologies affordable by various farmers groups from an economic and social stand point becomes inevitable if technological changes should be regarded in agricultural development programs. The aim of this research was to design, develop and evaluate a simple inexpensive yield monitoring system in order to provide a yield map for better production management decision making purposes suitable to socio-economic conditions prevalent in agricultural regions in central Iran. Therefore, these steps were taken:

– Development of an impact type grain flow sensor,

– Design and development of a yield monitoring system with all necessary components,

– Testing the system on two fields planted under winter wheat crop and,

– Plotting yield maps of the fields and interpretation of the results obtained from field experiments.

2 Material and methods

The system consisted of an impact flow sensor determining the mass flow of grain, the GPS receiver determining geographical position of the machine, two shaft encoders measuring the speed of the combine, an ultrasonic sensor measuring the actual cutting width, and a data logger which displayed values and saved them on a Mass Memory Card (MMC) (Figure 1).

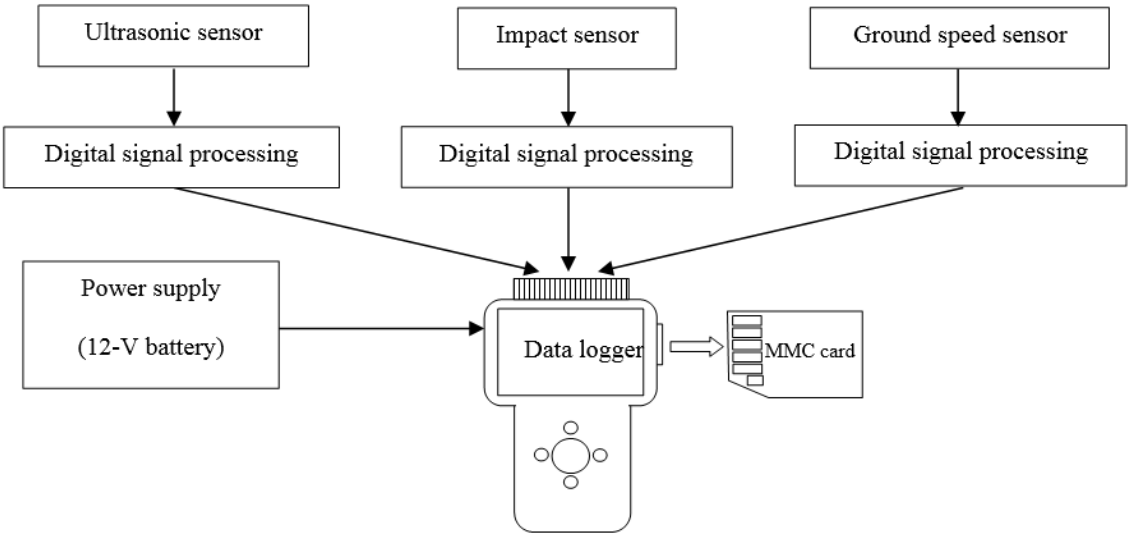

Figure 1 The block diagram of the yield monitoring system components.

An impact type sensor was developed to measure mass flow of wheat crop on a grain combine harvester. A load cell manufactured by BONGSHIN ® Company, series OBU with 1 kg capacity was selected and an impact curved plate was fabricated. In these types of sensors the impact force or moment caused by the change in momentum of the grain flow, is measured.

Fabricating the set-up, it was installed on top of the clean elevator and positioned in the transition housing between the paddle chain of the clean grain elevator and the loading auger of the clean grain tank. Figure 2 shows the linkage and set-up of the sensor.

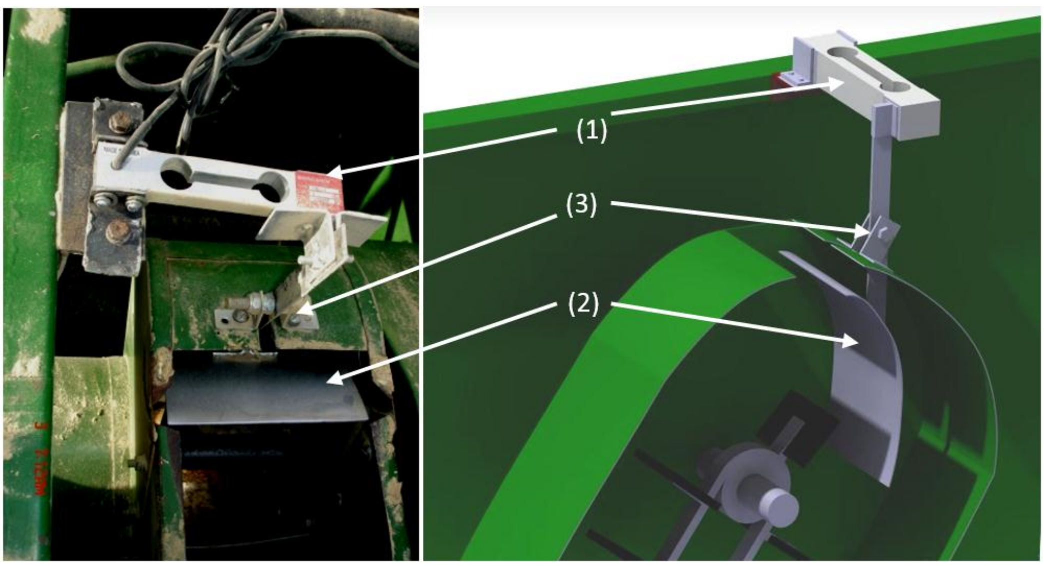

Figure 2 Sensor linkage and its position on the combine, (1) load cell; (2) impact plate; (3) and support.

After positioning the sensor, it was calibrated statically and dynamically and its calibration curve was plotted which related the mass flow to load cell signal. Dynamic calibration was done by a small grain tank equipped with two S-type load cell, manufactured by BONGSHIN ® Company, with 50 kg capacity, which was located in the combine tank. In this experiment, grain flow rate into the clean grain elevator was controlled, and variation in response from sensors was observed.

A data logger made by Industrial Control and Automation Division of Isfahan University of Technology (IUT), model DL7718 was used to record signals of all component of the system within every 5 s interval. The data logger was located beside driver's seat.

To plot an accurate yield map, an accurate GPS receiver that can determine the combine location while it is moving is needed. A commercial Leica® GPS receiver model SR-20 was chosen for the purpose. The GPS receiver had two antennas; one of them was placed on top of the combine which recorded rover data every 5 s and the other one that was as a reference, collected spatial property of one point during the whole harvest time. The errors were less than 2 m after the GPS data was processed in Leica Geo Office® software.

One of the components of a yield monitoring system is ground speed sensor. To determine combine forward speed, two shaft encoders manufactured by Tabriz Pajuh Co™ were connected to rear wheels of the combine. They were placed on rear wheels instead of front wheels in order to eliminate the effect of front driven wheel slippage. The harvested area was determined by multiplying the actual operating width of the machine by its forward travel distance between data points. The actual operating width was determined by means of an ultrasonic sensor produced by Industrial Control and Automation Group at IUT. It was located on the tip of the platform of the combine. The system components and their locations on the combine are shown in Figure 3.

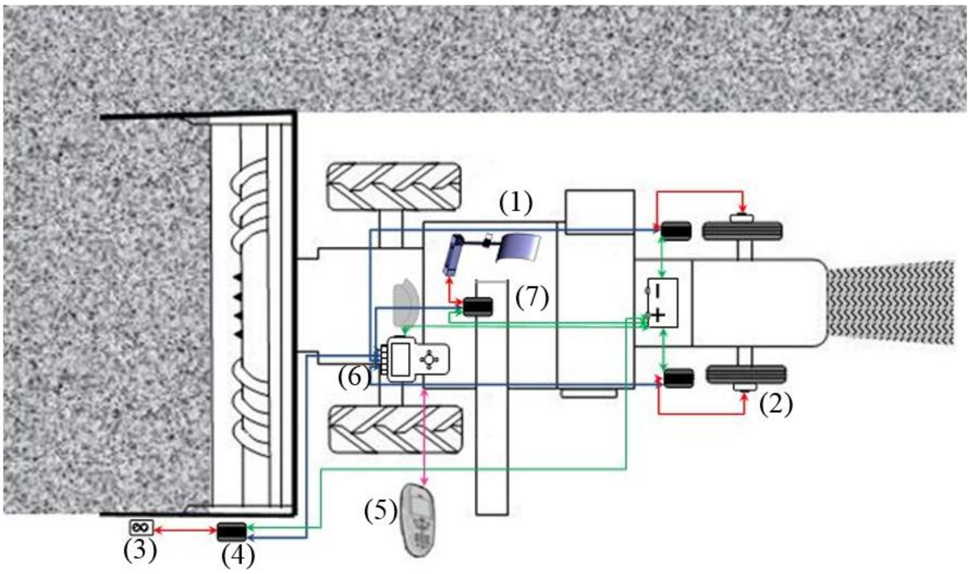

Figure 3 System components and their locations and wiring on the combine from top view: (1) mass flow sensor, (2) speed sensor, (3) ultrasonic sensor, (4) signal conditioners, (5) GPS receiver, (6) data logger, and (7) power resource

Two approximately 4 and 6 ha wheat fields in Fereidoon-shahr, Isfahan province in Central Iran, was chosen for this study. The fields are located at latitude 32° 57'N and longitude 50° 11'E (Figure 4). Cultivation in the fields was started on November 2009 and the seeding rate was 250 kg/ha. The overall soil texture of the fields varied from clay (C) to clay loam (CL). Average annual temperature of 9.3℃ and annual rainfall of 564.2 mm are climatic data of the experiment site. The irrigation system of the fields consisted of a solid-set sprinkler irrigation system with removable sprinklers.

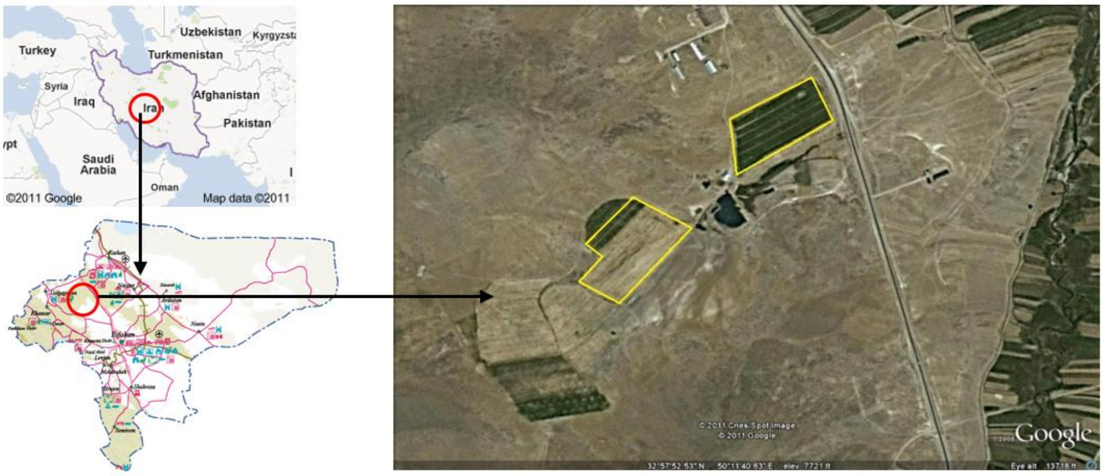

Figure 4 Maps of Iran, Isfahan and the fields of this study (the fields are highlighted)

To compare yield data of the system with actual yield of the fields, random sampling from some parts of the two fields was performed by hand harvesting. A quadrate frame 1 m by 1 m was used for hand harvesting. The average height of wheat stems, the number of grain per spike, grain moisture content, grain yield, 1000 grain mass and straw yield was measured at 5 randomly selected points of each field.

The equipped combine was a John Deere 955, with cutting width of 4.26 m. The speed of the combine during harvest was 3 km/h which was chosen based on crop and field conditions (ASAE D497.1). The other adjustments of the combine were applied based on manufacturer's recommendations. The harvest operation was started on August 2010 and lasted for 2 days.

The data of the sensors was saved in the MMC card in line with harvesting the fields with 0.2 Hz frequency (every 5 s). During the harvest operation, the load cell data was influenced by the harvester vibration and it had noise on its frequency. The data was filtered by Finite Impulse Response (FIR) in MATHLAB 2008 software. The FIR filter with 10-degree filtration, low pass with pass frequency equal to 0.15, was applied and the data was analyzed with Excel 2007 software. The voltage output of load cell was transformed into grain mass values by the calibration curve. The yield was calculated by following Equation 1:

$$\text{Yield (t/ha)} = \frac{\text{Mass flow (kg/s)}}{\text{Actual Width (m)} \times \text{forward speed} \left(\frac{\text{km}}{\text{h}}\right)} \times 3600 \qquad (1)$$

The semivariogram is a structural tool for depicting the spatial dependency in a realization of a mean-constant process. To create accurate spatial variability maps it is required to be modeled the surface values. Because of irregular trend in surface it is difficult to be modeled by a simple smooth mathematical function so it is described by a stochastic surface. Semivariogram is a modeling spatial variance which is a prior knowledge requirement for kriging (Buyong, 2007; Eltaib et al., 2002). Semi-Variance is defined by the following Equation 2:

$$\gamma(h) = \frac{1}{2n}\sum_{i=1}^{n}\{Z(p_i) - Z(p_i + h)\}^2 \qquad (2)$$

Where $\gamma(h)$ is semi-variance for interval distance class h, $Z(p_i)$ is measured sample value at point i, $Z(p_i+h)$ is measured sample value at point i+h and n is the number of pairs of data points of attribute Z separated by distance h.

Semivariogram is the graphical explanation of semivariance. Components of semivariogram which include fitted model type, nugget (C_0), sill ($C+C_0$), range (A_0), partial sill (C), portion $C/(C+C_0)$, coefficient (R^2) and reduced sum of square (RSS) were calculated by geostatistical analysis of GS^+ software.

The resulted grain yield data and GPS receiver data were entered in ArcGIS 9.3 software to be interpolated geostatistically by kriging technique through spatial analysis extension. For using kriging technique the distribution of data should be normal and if the distribution is not normal a transformation function should be applied in order to normalize the distribution. Thus, first the semivariogram of the data was calculated and a suitable model was fitted to data and then interpolation, the process of estimating a value at a given point from surrounding data, was done by kriging method which is the most common method to produce variability map.

3 Results and discussion

Figure 5 shows the result of static calibration of the load cell related to its output (V) to weight (g).

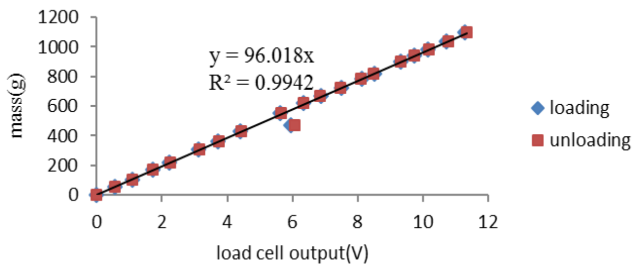

Figure 5 Load cell static calibration curve

The dynamic calibration curve which relates the mass flow rate to load cell signal output has illustrated in Figure 6. The curve was used in order to calculate yield of the farms.

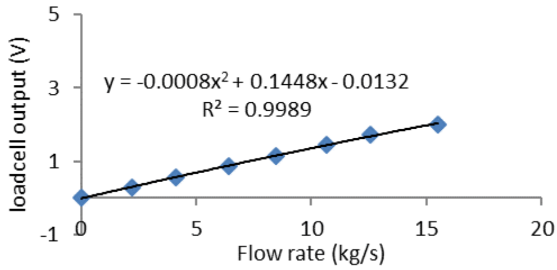

Figure 6 Load cell dynamic calibration curve.

Part of load cell output frequency curve and the filtered data curve are shown in Figure 7. Data was filtered to eliminate the noise on the output curve for better representation of the load cell functioning. The data was filtered by Finite Impulse Response (FIR) in MATHLAB 2008 software. The FIR filter with 10-degree filtration, low pass with pass frequency equal to 0.15, was applied and the data was analyzed with Excel 2007 software.

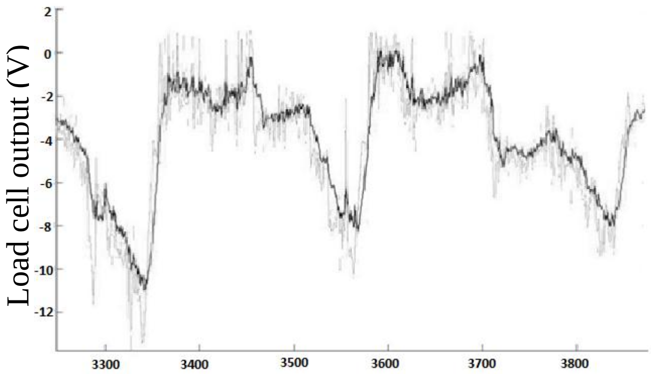

Figure 7- Part of the load cell output (light line) and filtered data (dark line).

In order to provide variability maps, results of semivariogram analysis for yield data of the two fields were applied. They are described by specific model throughout the range of data so; different variogram model types were checked to find the best fitting one. Isotropic variogram that demonstrates graphs of semivariance versus separation distance are shown in Figure 8. It presents the fitting curve of selected model for each farm yield values while lag distance in semivariogram analysis assumed 300 m.

$$\gamma(h) = \frac{1}{2n}\sum_{i=1}^{n}\{Z(p_i) - Z(p_i + h)\}^2$$

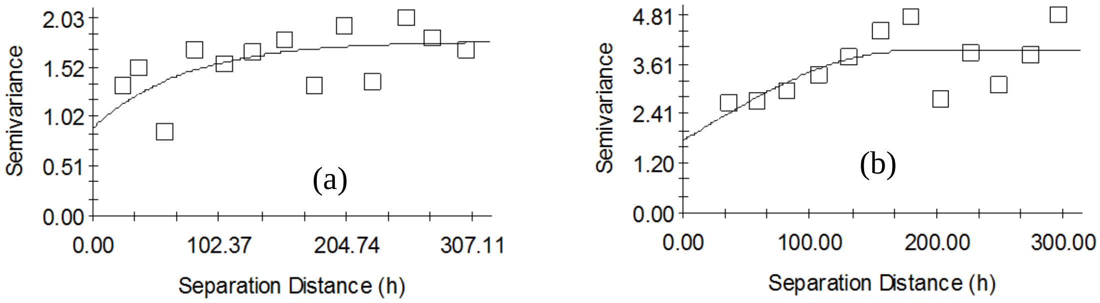

Figure 8 Isotropic variogram of the yield data of the two fields, (a) field1 and (b) field 2.

The fitted curve for related semivariance gives the values of sill, nugget, range and variogram fitting model as shown in Tables1 and 2.

Table 1 Summery statistics of the yield data

Field num.	Mean (t/ha)	Standard Deviation	Max	Min	Coefficient of variation ,%	Skewness	Kurtosis	Transformation Function
1	6.59	1.2	9.53	3.42	23.47	-0.18	1.8	Box-Cox
2	7.01	0.2	9.38	2.59	19.80	-0.1	3.1	Log

Table 2 Geostatistical description of yield of the fields

Field num	Model type	Partial sill	Nugget	Range	RSS	R^2	proportion
1	Exponential	1.79	0.89	21.62	0.83	0.34	0.50
2	Spherical	3.92	1.75	147.3	3.84	0.42	0.55

Descriptive statistics of yield data showed the coefficient of variation ranging from 23.47% for field 1 and 19.8% for field 2 which indicated the existence of variability in yield in the two fields. The variability in field 1 as indicated by the data is more than field 2. This could be also understood from geostatistical descriptions which showed that the range of influence in field 2 is less than field 1 and it indicated that the yield varied 2.43 t/ha over 23.7 m for field 1 and varied 2.00 t/ha over 49.5 m for field 2.

Yield maps provide detailed spatial information that is lacking in simple descriptive statistics. Spatial variability maps of the two fields are shown in Figure 9 and the histogram of the yield data of the fields is also illustrated in Figure 10.

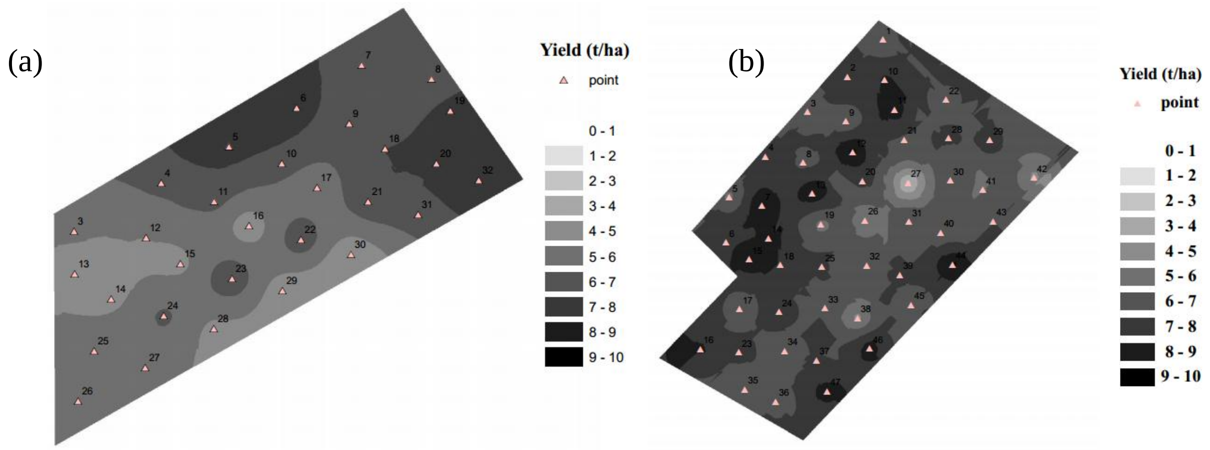

Figure 9 Yield maps (a) field 1, (b) field 2

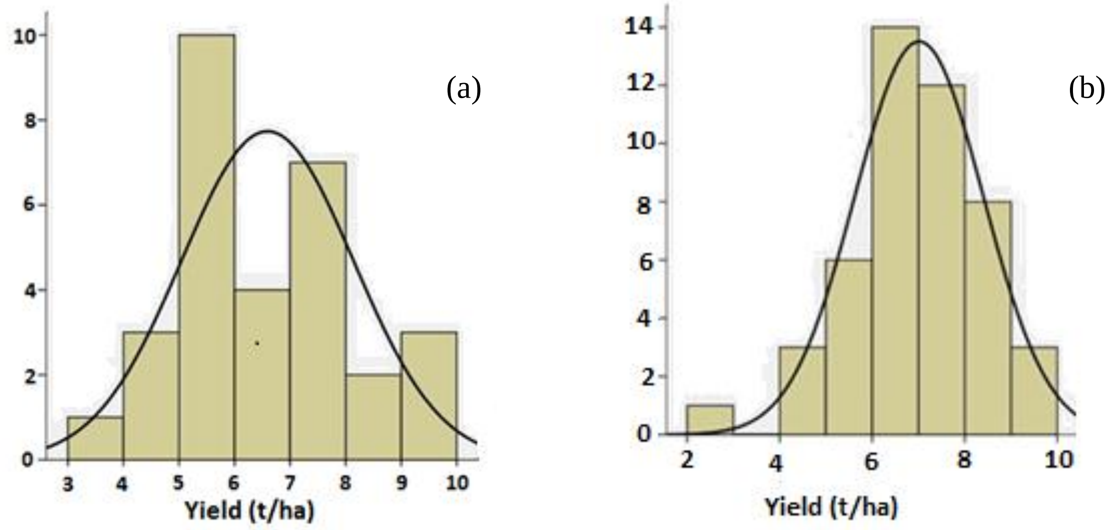

Figure 10 The histograms of (a) field 1, (b) field 2

Variations illustrated in the yield maps might have some causes other than parameters studied in this research. They might be due to differences in topographic condition of the fields, variations in soil texture of the fields 1 and 2, variability in fertilizer distribution or irrigation water distribution in the fields. Since both fields were irrigated by a solid set irrigation system, pressure differences across the points in both fields may have contributed to yield variations observed. Realizing the accuracy and proficiency of the yield monitoring system, hand harvest data could be a good indication for the systems performance validation. Table 3 shows some yield components from the fields obtained from hand harvesting.

Table 3 Hand harvest data

Field Num.		Height ,cm	Grain per Spike	Moisture content ,%	Grain Yield ,t/ha*	1000 Grain Mass,g*	Straw Yield , t/ha*
field1	average	76.85	29.34	6.57	6.35	26.21	7.62
	Std. Dev.	4.65	4.22	0.66	2.43	6.57	0.7
field2	average	84.55	35.85	7.27	7.71	25.77	8.78
	Std. Dev.	3.41	4.06	0.32	2.41	5.74	1.13

Note: * The wet based type was used in order to calculations.

Comparing the hand harvest yield and the yield monitoring system results for both fields, the system had an error of -3.64% for field 1 and 9.98% error for field 2. Based on Kormann et al. (1998) research findings, these errors are acceptable for impact type yield sensors. Vansichen and De Baerdemaeker (1991) developed an impact type mass flow sensor which had an error of 3.5% in field experiments. Their results are similar to findings for the sensor in this study for field 1. They mentioned that the slope of the field was the influential factor in increasing the error of the sensor. The errors for field 2 were higher since this field was steeper than field 1 and based on prior studies, the slope of the field was an important factor that influenced the accuracy of impact type sensor.

The results revealed that this system could be an alternative yield monitoring system with lower costs (less than one third price) compare to commercial yield monitoring systems.

4 Conclusions

Following conclusions were drawn from this research:

1. Based on the results obtained from the field experiments, the following conclusions were reached: 1. The mass flow sensor developed in this study and based on its performance could be considered as an effective tool in on-the-go measurement of crop yield and provides a fairly accurate estimation of true yield across different fields.

2. The mass flow sensor output was influenced by the combine vibration and there were noises on its overall frequency. Therefore, a filtering process should be applied to remove the noises in order to improve the quality of yield map and reduce errors.

3. The yield monitoring system had an error of -3.64% for field 1 and 9.98% error for field 2 having an acceptable error level reported by other researchers.

4. The slope of the field was an influential factor that would reduce the accuracy of the impact type sensor. Further study is recommended to explore ways to diminish the effect of slope on sensor performance in steep fields.

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