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Performance Evaluation of Hay Yield Monitoring System in Large Rectangular Baler

[1,2]Ahmed G. Kayad, [1,3]Khalid A. Al-Gaadi, [1]El-Kamil Tola,
[1]Rangaswamy Madugundu and [1]Ahmed M. Zeyada

[1]Precision Agriculture Research Chair, King Saud University, Riyadh, Saudi Arabia
[2]Agricultural Engineering Research Institute (AEnRI), Agricultural Research Centre, Giza, Egypt
[3]Department of Agricultural Engineering, College of Food and Agriculture Sciences,
King Saud University, Riyadh, Saudi Arabia

Abstract: Yield monitoring is one of the most important operations for efficient management of agricultural fields. One of the common methods used to monitor hay yield variability is to monitor the hay mass flow rate inside the baler chamber during hay baling process.Therefore, this study on a 10 ha field was conducted to investigate the performance of a hay mass flow monitoring system mounted on a large rectangular baler in estimating alfalfa hay yield. The monitoring system was used to monitor alfalfa hay yield at different baler settings (baler chamber pressure values of 5000, 6000 and 7000 kPa and forward speed values of 4, 8 and 12 km/h) that affected bale density, hence, yield monitor data accuracy. Data from the monitoring system was utilized to generate a georeferenced yield data points that were compared, for calibration purposes, to an actual georeferenced alfalfa hay yield data points. The actual hay yield was obtained by physically weighing the hay bales out of the study area. Results revealed that bale density was mostly affected by baler chamber pressure and high levels of forward speed. Alfalfa hay bale density was found to be correlated to the chamber pressure. On the average, bale densities of 181.3, 171.6 and 168.9 kg/m^3 were obtained at baler chamber pressure of 7000, 6000 and 5000 kPa, respectively. The monitoring system exhibited a good performance in hay yield estimation at different baler working conditions with an average R^2 value of 0.87 for the relation between monitor-estimated and actual yield.

Key words: Hay yield monitoring · Baling · Large rectangular baler · Precision agriculture

INTRODUCTION

Alfalfa (*Medicago sativa*) is considered as one of the most important forage crops to the farmers, as well as, to the dairy and livestock producers due to its high yields of high quality forage. Alfalfa is cultivated in every continent in more than 80 countries in an area exceeding 35 million ha. Because of its low rate of dry matter, low level of suger and high buffer capacity, alfalfa is commonly used as hay, as it is not suitable for ensilage [1].

Hay baling is characterized as one of most essential hay production operations, as it facilitates hay handling, transporting and storing. In addition, hay baling is a high-capacity one man operation with low harvest losses [2]. Hay balers are designed for gathering the cut hay from windrows and compressing it in round or square-shaped bales. Baling process is accomplished after three operations, namely: (i) forage cutting using mowing machines, which cut forage and discharge it in rows, (ii) windrowing process using a windrower, which gathers the cut forage into larger windrows of 1.0 to 1.5 m width and (iii) raking process using a rake machine that stirs the hay and turns it over for hay drying [3].

Hay Bale Density: Hay bale density formed by round balers ranged from 80 to 200 kg/m^3, while large square balers provided bales with densities ranging from 130 to 180 kg/m^3[4]. In silage baling, increasing baler forward speed from 6.4 to 8.8 km/h tended to decrease silage bale density, however, differences were not significant [5,6].

Corresponding Author: Ahmed G. Kayad, Precision Agriculture Research Chair,
King Saud University, Riyadh, Saudi Arabia.

The bale density is a function of the type of material, moisture content and the total force applied on the material moving through the baler chamber. The principle of controlling the bale density is based on squeezing the bale at two or four of its sides as it is discharged out of the baler chamber [2]. Lotjonen and Paappanaen [7] reported that the most important factor affecting bale density in large round balers was the bale chamber pressure, even when using different windrow sizes. They also found that increasing forward speed from 5.5 to 10 km/h decreased the bale density by 12%.

A dynamic weighing system to weigh individual square bales during the baling process was developed by Maguire *et al*. [8]. The weighing system was based on a load cell placed at the chute of the baler to determine each bale weight. Sun *et al*. [9] developed a dual sensor penetrometer to measure, at the same time, penetration resistance and moisture content to estimate bale density with the support of γ-ray image based analysis. They reported that the γ-ray image based analysis was an accurate technique for the assessment of bale density.

Hay Yield Monitoring: The amount or mass of harvested crop per unit area is defined as being the crop yield [10]. This yield was found to spatially vary within the same field [11], where mapping this variation (yield mapping) is considered as one of the fundamental elements of Precision Agriculture (PA). Biomass assessment to quantify the variations in crop yieldwithin a field is viewed as an important element in understanding the farming process. This understanding can greatly help improve farming practices, productivity and in the reduction of negative environmental impacts [12]. The traditional way of assessing biomass of forage crops is laborious and time consuming [13].

Many efforts have been made to monitor hay and forage crop yield by measuring feed roll displacement using load cells with springs [14], vertical displacement transducer [15] and linear potentiometer [16]. A round baler was equipped with a weighing system based on load cell to provide a monitoring system of forage crop yield during baling process [17]. The error associated with the developed monitoring system was less than 1% in static weighing. However, the resolution of yield maps generated using this system was limited to the size of the area from which a bale was produced.

Shinners *et al.* [18] developed a system for hay yield monitoring in large square balers composed of a star wheel encoder to measure bale displacement inside the baler chamber, which was correlated to the hay mass flow rates. Manufacturers of forage harvesting machines, such as John Deere and Krone, are presently implementing mass flow sensors in their machines to serve as yield monitoring systems. On the other hand, bale weighing system is integrated in most large square balers manufactured by New Holland, Hesston and Chalenger [19].

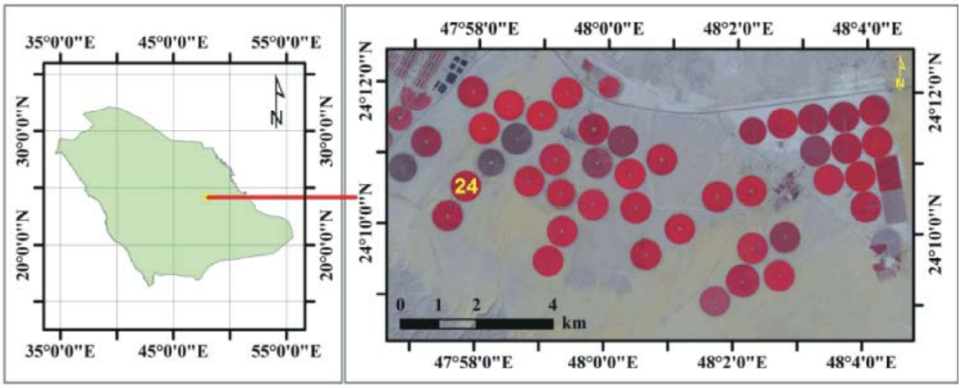
More efforts are needed in the area of hay yield monitoring, as only a little work has been done in monitoring crop yield variability for forage crops as compared to grain, potatoes or cotton. In addition, most of the work on hay yield monitoring has focused on monitoring in round baler and forage harvester and less efforts have been done to monitor hay yield variability or mass-flow rate in rectangular balers [18]. Therefore, this study was designed to reveal the effect of baler chamber pressure and forward speed on produced bale density. In addition, the yield estimated by the monitor system was calibrated against actual yield to verify the monitor output.

MATERIALS AND METHODS

This study was conducted on a commercial farm (Todhia Arable Farm - TAF) located in Al-Kharj region of Saudi Arabia. The climatic zone was classified as a narid and the soil texture was determined as sandy clay loam. One of the farm fields cultivated with alfalfa under a center pivot irrigation system was designated to be the study field within the cordenates of 24°10' 37" N, 47°57' 42" E and 24°10' 23" N, 47°58' 03" E. The variety of the alfalfa cultivated in this field was “Super Fast” and the planting date was October 24, 2012. A 10 ha area was thought to be sufficient and reasonably practical to perform the study. Therefore, the study took place in the west half (an area of 10 ha) of the field number 24 (Fig. 1) at spans 4, 5 and 6. The study was conducted on cut number 5 dated July, 2013.

A large rectangular baler (CLAAS model Quadrant 3200), shown in Fig. 2, was used in this study to bale alfalfa hay. The baling channel dimensions were 3, 1.2 and 0.7 m for length, width and height, respectively [20]. A 175 hp John Deere tractor (Model 7810) was utilized to trail and operate the baler at a power of 160 hp, PTO shaft speed of 1000 rpm, pickup width of 2.1 m and ram strokes speed of 51 rpm.

A hay yield monitoring system (model 500 of Harvest Tec) was employed to measure the alfalfa yield out of the study field. This system provided data on the mass flow



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Todhia Arable Farm (TAF)

Fig. 1: Experimental site

Fig. 2: Large Rectangular baler model CLAAS (Model Quadrant 3200) trailed by John Deere tractor (Model 7810)

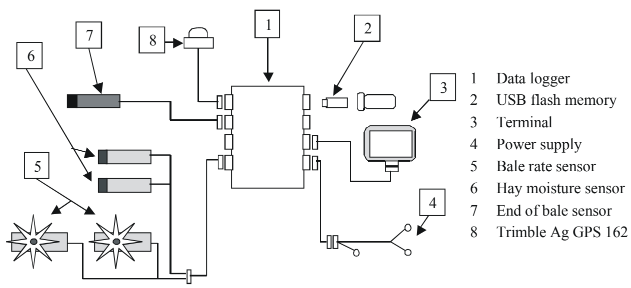

Fig. 3: Hay yield monitoring system

Fig. 4: Hay mass flow and end bale sensors

rate, moisture content and wet and dry yield. It was also capable of georeferencing the bales using a Trimble GPS receiver (Trimble Ag GPS 162). A schematic of the yield monitoring system is depicted in Fig. 3, however, related sensors are shown in Fig. 4.

A calibration for the Moisture Content (MC) sensor was performed to evaluate the performance of this sensor in estimating baled hay moisture content. At the baling time, the hay mass flow sensor was recording data on the quantity of yield. After the production of each ten bales, three samples were taken from each bale for laboratory MC analysis. The three samples were mixed into a composite sample and weighed to determine the wet weight. The composite samples were oven dried at 70°C for 48 hours, then weighed again to determine the dry weight and MC%. The laboratory-calculated MC was

Fig. 5: GPS calibration

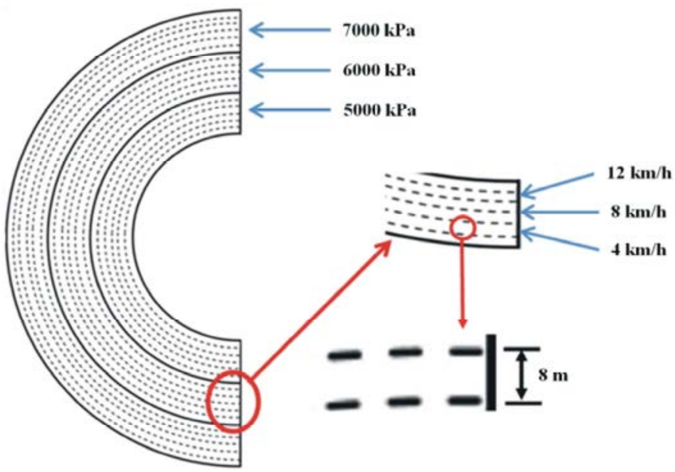

Fig. 6: Experimental layout

correlated to the sensor-determined MC readings and an R^2 value of 0.86 (P<0.01) was determined for the correlation.

To georeference yield, the hay mass flow monitoring system used a Trimble GPS receiver (model: AgGPS162) mounted on the top of the baler for field location determination. The Trimble receiver was calibrated using another calibrated Omnistar GPS receiver (model: 9200 G2), which produced an accuracy of less than 2m (Fig. 5).

The effect of baler chamber pressure and forward speed on bale density was field investigated using a split-plot design with ten replications. Three levels of baler pressure (5000, 6000 and 7000 kPa) at the time of baling were considered as the main plots and were allocated for span 4, 5 and 6 of the study field. Three different baling speeds (4, 8 and 12 km/h) were applied on each main plot and were considered as the sub-plots, however, each bale acted as a replicate. The experimental layout is shown in Fig. 6.

The large rectangular baler with the installed hay mass flow monitor was utilized to perform the study field, where alfalfa hay was baled at three different baler chamber pressure settings (5000, 6000 and 7000 kPa) and at three different forward speeds (4, 8 and 12 km/h) for each pressure setting. Each combination of these treatments was applied to ten bales, which served as replicates. During field study, two bales after each treatment were not considered for data collection in order to ensure the elimination of any effect of a previous treatment on a current treatment. At the time of baling, the hay mass flow monitoring system recorded each bale starting position, time and MC%, crop flow rate inside the baler chamber and yield spatial variability. Distribution of bales inside the field is shown in Fig. 7. As a complete baling was performed following the different study treatments, the bales were tagged with numbers that matched the numbers assigned to them by the monitoring system. Totalbales were weighed in the field using a weighing scale with an accuracy of ±5 kg. The wet weight of a total of 105 bales was recorded along with corresponding bale numbers. The hay mass flow monitor system data was downloaded for statistical analysis.

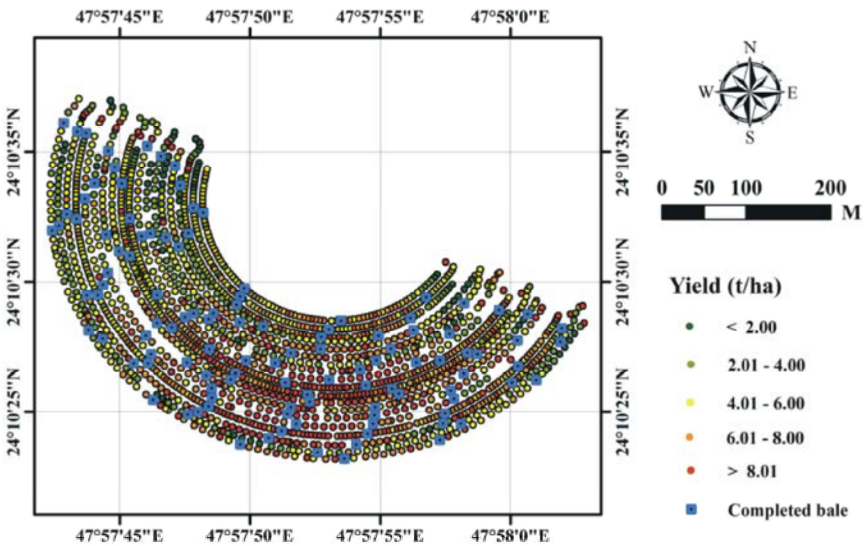

Fig. 7: Distribution of bales inside the field

RESULTS AND DISCUSSION

Alfalfa Hay Bale Density under Different Baler Settings: Ninety bales of alfalfa hay were used to study the effect of different baler chamber pressure settings (7000, 6000 and 5000 kPa) and forward speed (4, 8 and 12 km/h) on produced bale density. Regardless of the settings, the produced bale out of the used large rectangular baler was 2.2, 1.2 and 0.7 m in length, width and height, respectively, with a volume of 1.85 m^3. Using a split plot design with ten replicates for each treatment, SAS statistical software program (SAS Institute Inc., Cary, North Carolina, USA) wasutilized to analyze the results of bale density investigation under the different operating conditions (chamber pressure and forward speed).

In general, results of the investigation revealed that the bale density was found, on the average, to be proportional to baler chamber pressure at all ground speed levels (Table 1). Baling alfalfa hay under baler chamber pressure of 7000, 6000 and 5000 kPa produced an average bale density of 181.3, 171.6 and 168.9 kg/m^3, respectively. However, baler forward speed introduced a significant effect on bale density in high speed only (12 km/h), which increased hay bale density from 173 to 176 kg/m^3. For instance, the bale density at a speed of 8 km/h increased by 7.5% as the chamber pressure increased from 5000 to 7000 kPa.

Considering individual data points, the utilized large rectangular baler produced alfalfa balesat densities ranging from 160.5 kg/m^3 to 191.0 kg/m^3 at the different baler working conditions used in this study. The major factor that affected bale density was found to be the baler chamber pressure, which was in agreement with the results presented by Lotjonen *et al.* [7] in large round balers. They also reported an average hay bale density of 171 kg/m^3 for reed canary grass, which was compareable to the average bale density over all test repetitions included in this study of 174 kg/m^3. These findings are inline with the results of Paappanen *et al.* [4], which indicated a hay bale density range of 130 to 180 kg/m^3 for large square baler.

It is clear that total resistance applied on alfalfa hay while moving through the baler chamber increased with increasing baler pressure, which explains the reason for increasing bale density. During field experiments, it was noted that suitable baling pressure was between 5000 to 7000 kPa for alfalfa, as lower pressure produced loose bales and higher pressure caused twine cutting and deformed bales.

Performance Evaluation of the Hay Mass Flow Monitoring System: Linear relationships were found between flow monitoring system estimated and actual yield data points at all studied baler chamber pressure values. The R^2 values determined for these relationships were 0.89, 0.86 and 0.86 ($P<0.01$ for all) for the pressure settings of 7000, 6000 and 5000 kPa, respectively. Calibration equations at each chamber pressure setting, as well as for all the three pressure settings combined, are shown in calibration graphs in Fig.8. Using the same system, a study by Shinners *et al.* [18] revealed an R^2 value for the relationship of 0.94. The baler hay mass flow

Table 1: Alfalfa bale density at different values of baler chamber pressure and forward speed

Baler chamber pressure (kPa)	Forward speed (km/h)	Mean bale density (kg/m^3)	Std. Dev.
7000	4	182.5	3.01
	8	179.1	2.36
	12	182.3	4.53
6000	4	169.5	3.64
	8	171.6	3.70
	12	173.7	2.00
5000	4	168.0	7.28
	8	166.6	3.44
	12	172.2	4.38

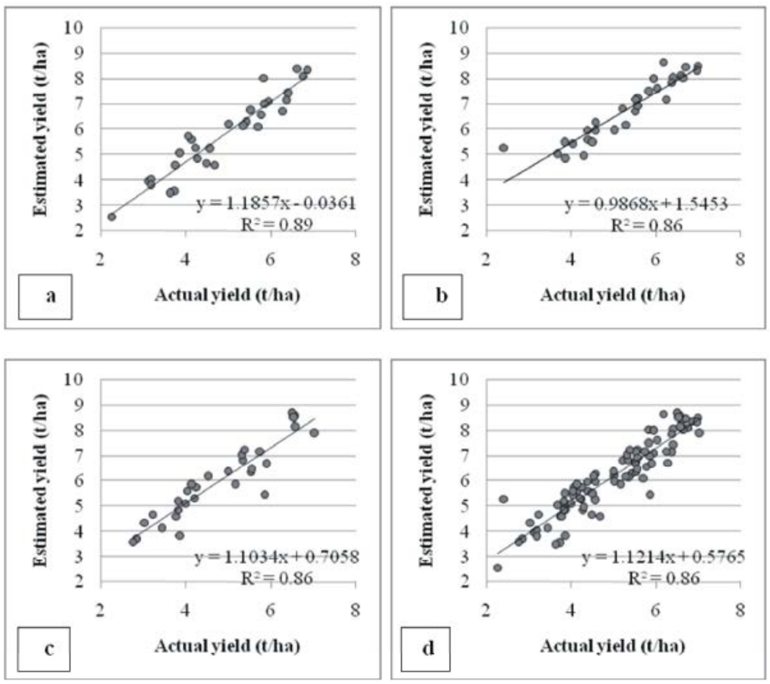

Fig. 8: Estimated yield *versus* actual yield at a baler chamber pressure of a: 7000 kPa, b: 6000 kPa, c: 5000 kPa and d: at all baler chamber pressure settings

monitoring system used the displacement of an amount of hay inside the baler chamber as an indicator of estimated yield [18]. The density of this amount of hay was not taken into consideration, to which the difference between estimated and actual yield can be attributed even at the same baler working conditions. It is thought that more accurate estimated yield, thus more accurate yield map, can be obtained if the crop mass flow data could be combined with bale density data. For example, adding another sensor for bale dynamic weighing described by Maguire *et al.* [8] or estimating bale density with the support of γ-ray as described by Sun *et al.* [9] could be suitable procedures to increase estimated yield accuracy.

The hay mass flow monitoring system used in this study recorded yield data points every three seconds, producing larger number of yield field data points (300 point/ha) at low forward speed of 4 km/h compared to that (100 point/ha) produced at the high speed of 12 km/h. The theoretical distance between two consecutive field data points was 10, 6.7 and 3.3 m for baler forward speed of 12, 8 and 4km/h, respectively. Therefore, the resolution of the generated yield map was inversely proportional to the baler ground forward speed. Given that the width of the baler was 10m, the grid size (resolution) of the generated yield maps was calculated at 80, 53 and 27 m^2 at the ground speeds of 12, 8 and 4 km/h, respectively. These grid sizes were less than the expected at the specified forward speeds, which was attributed to the fact that the baler actual speeds under field conditions were less than the desired ones. The low forward speed producing higher map resolution can be used for research purposes to obtain more accurate results. In agricultural practice on a farm scale, a trade off is always established between map resolution and machine field capacity.

For a practical practice, higher forward baler speed of up to 15 km/h can be used on a farm scale and can still produce a fairly suitable resolution yield map and an acceptable machine field capacity.

CONCLUSIONS

This study proved that increasing baler chamber pressure caused a significant increase in alfalfa hay bale density. On the average, alfalfa hay bale densities of 181.3, 171.6 and 168.9 kg/m^3 were produced at baler chamber pressure values of 7000, 6000 and 5000 kPa, respectively. In addition, the mass flow monitoring system of the utilized baler was found to be reliable in estimating hay yield at all different baler operation conditions (chamber pressure and forward speed) investigated in this study. An average R^2 value of 0.86 was determined for the relationship between monitor-estimated and actual yield.

Recommendation: It is recommended to use bale weighing system, such as a load cell, to estimate bale weight as an additional sensor to the yield monitoring system which can improve system accuracy. This addition can provide the weight directly, not from calculations.

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