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ORIGINAL ARTICLE

Impact of the Baler Chamber pressure on Alfalfa bale density and Penetration Resistance

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ABSTRACT
Alfalfa hay bale weight and density are considered as important parameters characterizing the produced bales. Therefore, a study was carried out for the assessment of the impact of the baler chamber pressure on alfalfa hay bales produced by a large rectangular baler in terms of bale weight, density and penetration resistance. The study was conducted in a farm located in the eastern region of Saudi Arabia. Results indicated that the increase in the baler chamber pressure associated with a significant increase in alfalfa bale dry weight; hence, bale dry density (R^2 = 0.84, P-Value = 4.23E-5), as well as a significant increase in the average bale penetration resistance (R^2 = 0.75, P-value = 0.053). The mean dry weight of 278.0, 298.5 and 318.2 kg, with mean bale dry densities of 150.5, 161.6 and 172.2 kg m^{-3}were recorded for the bales produced under baler chamber pressures of 5000, 6000 and 7000 kPa, respectively. On the other hand, the average penetration resistance of the produced bales through the entire penetration depth (0-45 cm) was 736.9, 789.6 and 1028.7 kPa for baler chamber pressures of 5000, 6000 and 7000 kPa, respectively.
Keywords: *Alfalfa hay, rectangular baler, baler chamber pressure, penetration resistance*

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INTRODUCTION

Alfalfa (*Medicago Sativa*) is an important forage crop for dairy farms to feed animals because of its high protein contentand other nutrients andhigh digestibility [1]. The immediate problem which faces farmers after cutting alfalfa for producing hay is to store the produced hay in a safe manner. Hence, high amount of moisture must be removed from the harvested grass before storing the hay. Different kinds of machines can be used for this purpose, such as tedders, turners, side-delivery rakes, rollers and crimpers [2].After hay becomes dry, a swather machine is usually used to swath the hay into rows for preparing it for the final baling process. Baling hay is one of the essential operations performed to facilitate handling, storing and transporting the harvested hay. In addition, field baling of harvested forages is a high-capacity and one man operation with low harvest losses [3]. Balers are designed to pick up hay or straw from a swath, compress it to specific dimensions and tie each bale with twine [2].The hay bale density is a function of the type of the material and its moisture content and the total resistance applied on the material through the baler chamber. The principal method to control the bale density is by squeezing together two sides or four sides at the discharge of baler chamber [3].Large rectangular balers, which are commonly used for hay baling, greatly vary based on their feeding mechanism. Lotjonen and Paappanaen [4] reported that large square baler with a pre-compression chamber resulted in the best shaped and densest bales for red canary grass. In large round balers, the most important factor that affects the bale density is the bale chamber pressure, even when using different forward speeds and different windrow sizes. In round baling, there are a few studies focused on baling very dry and coarse material; however, most studies focused on silage baling, where the material is softer with high moisture content (40-75%).
The most important parameters characterizing the produced hay bales are the bale weight, density and nutrient content. Sun et al. [5] developed a dual sensor penetrometer to simultaneously measure

penetration resistance and moisture content to estimate the bale density with the support of γ ray image based analysis. He reported that γ ray was an accurate technique for the assessment of bale density. The objective of this study was to investigate the impact of the baler chamber pressure of a large rectangular baler on the characteristics of alfalfa hay bales, represented by the weight, density and penetration resistance.

MATERIALS AND METHODS

Study area

This study was conducted in Todhia Arable Farm (TAF)) located between Al-Kharj and Haradhcities in the eastern region of Saudi Arabia between the latitudes of 24º10' 22.77" and 24º12' 37.25" N, and longitudes of 47º56' 14.60" and 48º05' 08.56" E. One of the farm fields (number 24) cultivated with alfalfa under center pivot irrigation system was designated as the study field. The variety of alfalfa cultivated in this 50 ha field was “Super-Fast” and the planting date was October 24, 2012. The study was carried out on the west half of the field within the span number 4, covering an area of 2.5 ha. The study was conducted on alfalfa cut (harvest) number 4made on 15June, 2013.

Alfalfa hay baling process

A large rectangular baler (CLAAS,Model Quadrant 3200) was used in this study to bale Alfalfa hay. This model of balers required a power of 160 hp, aPTO shaft speed 1000 rpm, and it has pickup width of2.1m, a ram strokes speed of51rpm, and a baling channel dimensionsof3, 1.2 and0.7 m for length, width and height, respectively**[6]**. For operating and towing the baler, a farm tractor of175 hp and a PTO shaft speed was 1000 rpm (John Deere Model 7810)was used.

A cone index penetrometer manufactured (Field Scout,Model SC900) was used in this experiment to estimate alfalfa bale density. This device records the penetration force and the corresponding depth using a load cell and an ultrasonic sensor. To determine the weight of the produced alfalfa bales, a weighing scale facility of the farm, with an accuracy of ±5 kg was used.

Execution of the experimental work

Alfalfa crop was first mowed using a self-propelled reciprocating mower. After three days of sun drying of the cut crop, a hay raking process had been carried out, using side delivery rakes, so as to prepare alfalfa hay for the subsequent baling process.

The large rectangular baler, towed with farm tractor (Figure **1**), was used for baling alfalfa hay using three different baler chamber pressures of 7000, 6000 and 5000kPa. These treatments applied to six bales for each pressure. Immediately after completing the baling process, each bale was given a number using a spray paint (Figure 2).

At the time of baling, alfalfa hay samples (a composite of 3-5 samples) were taken from each of the studied bales for the determination of hay moisture content (MC)in the laboratory. The cone penetrometer (Model: Field Scout SC 900)was used to measure the penetration resistance for each of the studied balesfor a depth range of 0 – 45 cm from the top of the baleas shown in Figure **3**, with a depth increment of 2.5 cm. Penetrometer readings were taken from three sampling points for each of the studied bales.

RESULTS AND DISCUSSION

Impact of the baler chamber pressure on alfalfa hay bale weight and density

The weight of the produced bales was assessed against the baler chamber pressure by a random selection of six bales representing each of the three investigated bale chamber pressures (5000, 6000 and 7000 kPa). The results of the weighed alfalfa hay bales (Table 1) indicated that the baler used in this study performed the baling process in a precise manner reflected in the low values of the coefficient of variation (CV) of 2.37, 2.85 and 2.48% under the baler chamber pressures of 5000, 6000 and 7000kPa, respectively. On the other hand, the baler chamber pressure induced a significant impact on the weight of the produced bales, as the bale weight increased significantly with the increase in the bale chamber pressure (R^2 = 0.84, P-Value = 4.23E-5), with a mean dry weight of 278.0, 298.5 and 318.2 kg for the bales produced under bale chamber pressures of 5000, 6000 and 7000 kPa, respectively. The same was reported by Han et al. [7] for pearl millet [*Pennisetumamericanum (L.) Leeke*] that the higher baling pressure significantly increased both mass and density of bales.

The density of the produced alfalfa hay bales ranged from 146 to 177.6 kgm^{-3}, falls in range previously described by Paappanen et al. [8] for large square bales (130 – 180 kg m^{-3}). It is obvious that alfalfa bale dry density significantly increased with the increase in the baler chamber pressure (R^2 = 0.84, P-value = 4.23E-5), resulting in mean values of 150.5, 161.6 and 172.2 kg m^{-3} for chamber pressures of 5000, 6000 and 7000 kPa, respectively. The same was reported by Afzalinia and Roberge [9] that there is a direct relationship between the applied pressure and the forage material bulk density.

Impact of the baler chamber pressure on alfalfa hay bale resistance to penetration

The cone penetrometer measurements were taken from the top surface of the produced bales to a depth of 45 cm inside the bale.The results(**Figure 4**)indicated that,on the average, alfalfa hay bale resistance to penetration increased with the increase in depth. Also, it was observed that the increase in the baler chamber pressure was associated with a significant increase (R^2 = 0.75, P-value = 0.053) in the average penetration resistance of the bale through the entire penetration depth. The average penetration resistance, for the entire penetration depth (0-45 cm) was 736.9, 789.6 and 1028.7 kPa for the baler chamber pressures of 5000, 6000 and 7000 kPa, respectively.

The impact of the baler chamber pressure on the bale resistance to penetration is because of its significant impact on the bale density. Hence, as indicated in **Figure 5**, the bale resistance to penetration increased with the increase in the bale density.

Table 1. Impact of the baler chamber pressure on alfalfa hay bale weight and density.

	Bale Dry Weight, kg			Bale Dry Density, kg m^{-3}		
Bale No.	**5000 kPa**	**6000 kPa**	**7000 kPa**	**5000 kPa**	**6000 kPa**	**7000 kPa**
1	284.6	282.9	309.4	154.0	153.1	167.4
2	273.0	304.1	325.7	147.7	164.6	176.3
3	284.1	305.5	311.2	153.7	165.3	168.4
4	269.8	295.1	328.2	146.0	159.7	177.6
5	273.7	303.8	320.6	148.1	164.4	173.5
6	283.1	299.7	313.9	153.2	162.2	169.8
Mean	**278.0**	**298.5**	**318.2**	**150.5**	**161.6**	**172.2**
St. Dev.	**6.6**	**8.5**	**7.9**	**3.6**	**4.6**	**4.3**
St. Error	**2.7**	**3.5**	**3.2**	**1.5**	**1.9**	**1.7**
CV (%)	**2.4**	**2.9**	**2.5**	**2.4**	**2.9**	**2.5**

Figure 1. Baling process of alfalfa hay.

Figure 2. Alfalfa bale numbering process.

Figure 3. Measurements of bale penetration resistance using the cone penetrometer.

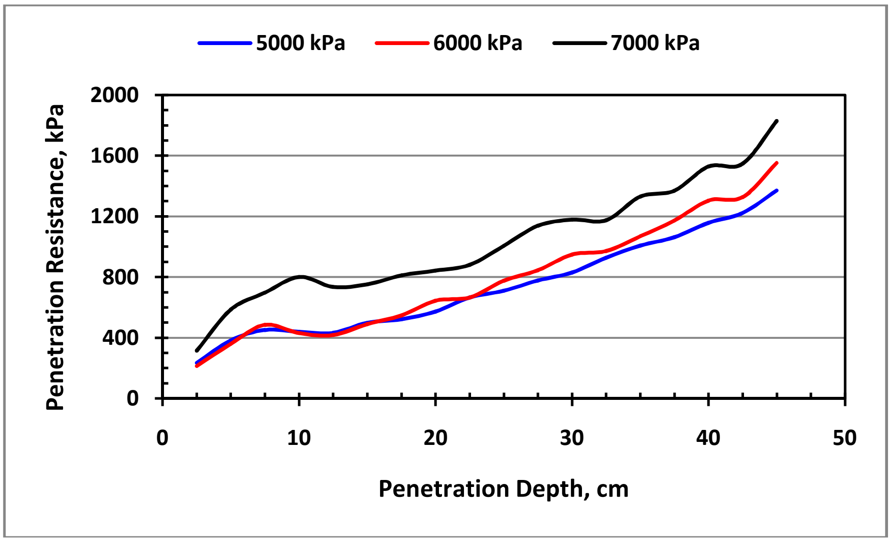

Figure 4. Average bale penetration resistance under different baler chamber pressures.

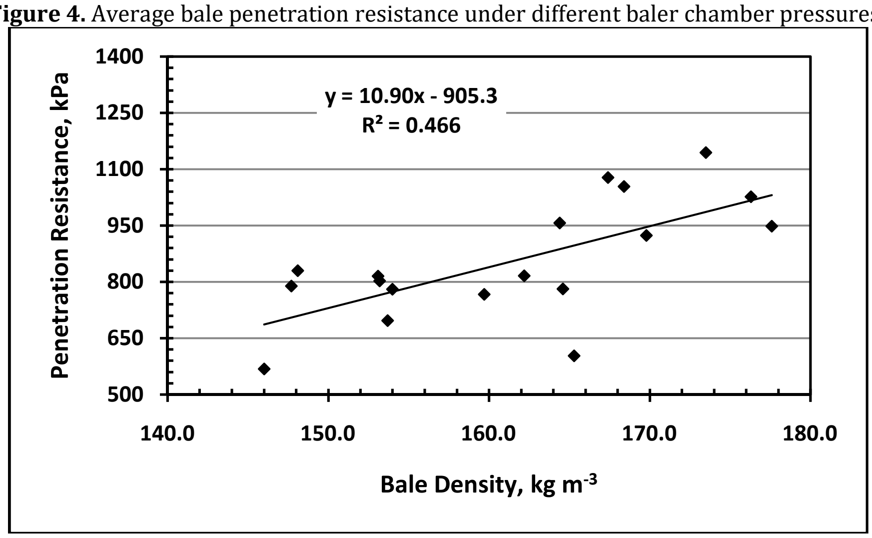

Figure 5. Relationship between the bale density and penetration resistance.

CONCLUSIONS

A study was conducted to investigate the impact of baler chamber pressure on alfalfa hay bale weight, density and penetration resistance. The following conclusions summarize the results of this study:

- The bale weight as well as the dry density increased significantly with the increase in the bale chamber pressure resulting in a mean dry weight of 278.0, 298.5 and 318.2 kg and a mean dry density of150.5, 161.6 and 172.2 kg $m^{-3}$for the bales produced under bale chamber pressures of 5000, 6000 and 7000 kPa, respectively.
- The increase in the baler chamber pressure was associated with a significant increase in the average penetration resistance of the bale through the entire penetration depth(0-45 cm); resulting in average penetration resistance values of 736.9, 789.6 and 1028.7 kPa for baler chamber pressures of 5000, 6000 and 7000 kPa, respectively.
- Finally, studding hay bale penetration resistance will help in the design of other machines like hay bale choppers and machines used to handle bales.

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