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Characterization of Highly Compressed Timothy Hay (*Phleum pratense*) at Different Levels of Moisture Content

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Abstract

Timothy hay was compressed using a laboratory hydraulic press. The applied pressure was increased from 0.0 to 21.0 MPa at intervals 3.5 MPa. The moisture content of hay varied from 7 to 20% wet basis (wb). During each compressing interval, the thickness of compressed hay was measured and the density of the resulting bales was calculated. In general, the density of the bales increased and their thicknesses decreased with the applied pressure, however the trends were not linear. The maximum bale density was about 1163 kg/m^3 which occurred at 21 MPa pressure for both 16% and 20% moisture levels. The 16% moisture content (MC) hays resulted in more dense final bales.

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Introduction

Hay stalks, after being harvested and field dried, are baled using various bale making machines. The main objective of baling are ease and less cost of handling, storage and transportation. The field bales are produced in different sizes and weights. In the area where the production is high, the large square balers are used to make bales with a weight of up to 900 kg and a density of about 150 kg/m^3. For export purposes, the large square bales are usually further processed at the baling operating plants where they are highly compressed to a density of about 500 kg/m^3.

In Canada the dominant cultivar of hay is timothy (*Phleum pratense*). Considerable amount of highly compressed timothy is regularly exported to Japan. Possible infestation of hay by Hessian fly, *Mayetiola destructor* (Say), is a concern of Japanese quarantine regulators. The current established quarantine security protocol between Canada and Japan requires the inspection of the hay for Hessian host plants (Tabil et al. 1999).

In Canada visual inspection is still the only current method for detecting the Hessian fly host plants in exporting hay. Development of a procedure that ensures the destruction of the Hessian fly puparia in the baled hay is to the interest of both importing and exporting countries. Alternative economical, safe and environmentally friendly methods for disinfestation of hay bales have been the subject of research efforts for the past two decades. Yokoyama et al. (1993) developed a multiple-quarantine treatment of compression and fumigation of bales which ensured 100% mortality of Hessian fly puparia. Yokoyama et al. (1994) indicated direct pressure of 20.6 kPa was sufficient to rupture the pupa of Hessian fly. Sokhansanj et al. (1992) and Opoku et al. (2001 and 2002) studied on thermal destruction of Hessian fly pupa and during field and laboratory studies. In general pupa is destroyed at temperatures above 55°C, however the uniform transfer of heat through the hay bales was indicated to be the prevailing problem.

Laboratory studies by Shaw et al.(2004) revealed that compressing the bales is an effective way to disinfestate the exporting hay. In their experiments the seedling containing pupa placed in the bales and compressed at 10 or 12 MPa pressure. In their laboratory experiments they achieved 100% mortality of the pupa. Thus, high compression of bales has both potential of a suitable means of size reduction and an effective means for disintensification of the bales. With advances in compression equipment and development of double-compression presses, there is a more promising opportunity for disinfestations of hay bales using high compression process. Currently the hay for export is compressed at about 10 MPa.. With increase in compression technology it is becoming more possible to compress hay to above 15 MPa. Knowledge of the changes in density and volume of the timothy hay under with various moisture content and increased pressures will be useful for efficient storage, handling and transportation of the bales. Thus, the objectives of this study were: a) to investigate the change in density and volume of bales under increased pressures ranging from 0 to above 20 MPa and b) to determine an optimum moisture content for maximum density of bales.

Material and Methods

The timothy hay stalks for use in this project were acquired from Elcan Forage Inc., Broderick, Saskatchewan. The initial moisture content of the hay was about 11% wet basis (wb). For the experiments, the moisture content was adjusted to 7, 12, 16 and 20% wb. For 7% moisture, the hays were left for a period of 10 days at room temperature until an equilibrium moisture content was reached. For the moisture of 12% and above, a calculated amount of distilled water was evenly sprayed on the hays in plastic bags and the bags were kept at 5°C for minimum 7 days.

The compression of the hays was performed using a hydraulic press (Figure 2). The press consisted of a double-way hydraulic cylinder which driven by a 4.0 hp electric motor. The press was capable of developing up to 30 MPa pressure. A 288 × 125 × 125 mm compression chamber was used for placing the hays inside it. The cross sectional area of the compression chamber was designed in such a way that the resulting pressure on the top surface of hay was the same as the gauge pressure of the hydraulics cylinder.

Fig.1. The hydraulic press used for compressing hays.

For density studies, 200 g of hay stalks was placed in the compression chamber and the pressure was increased in a stepwise manner with 3.5 MPa intervals to a maximum pressure of 21 MPa. At the end of each stage, the applied load was recorded and the stroke length of the piston was measured. The same test procedure was performed for different levels of moisture content. Each test was repeated three times and the average of the three replicates was used for analysis of the results and discussions.

After compressing, the bales were kept at room environment (about 25°C and 40% RH) and they were allowed to loose moisture until equilibrate with the surrounding. Then the weight of each bale was determined and the changes in the density of bales were calculated.

Results and Discussions

The results of decrease in the thickness of the hay during are presented in Table I. The last row of the table indicates that the lower moisture content hays resulted in larger bale thickness. This is generally to the friction of the hay stalks which is a higher when moisture content is lower. Within the limit of the tests, the thickness reaches the same amount when moisture content reaches 16% and above.

Table I. The thickness changes of the hay as applied pressure is increased.

	Thickness (mm)			
pressure	7%	12%	16%	20%
0.0	284	284	284	284
3.5	28.5	29	21	18
7.0	24.5	23	16.5	14.5
10.5	21	18	14	14
14.0	19	15	12.5	12.5
17.5	17	13	11.5	11.5
21	16	12	11	11

The graph of bale thickness versus the applied pressure is shown in figure 2. The graph indicates a sharp decrease in the height of the bales by applying 3.5 MPa pressure. Then the size of the bales become close to each other. To get a better under standing of the changes in the thickness of the bales at different level of pressure and moisture content, the same data but for the pressure range of 3.5 to 21 MPa are plotted in Figure 3 As it can be seen from the graph, at 3.5 MPa, the 7 and 12% moisture content hays are compressed almost to the same thickness, while the 16 and 20% moisture content hays are respectively compressed more. The thickness is decreased almost exponentially as pressure is increased for all levels of moisture content. But for the 16 and 20% levels the thicknesses emerge at 10.5 MPa and remain the same after that.

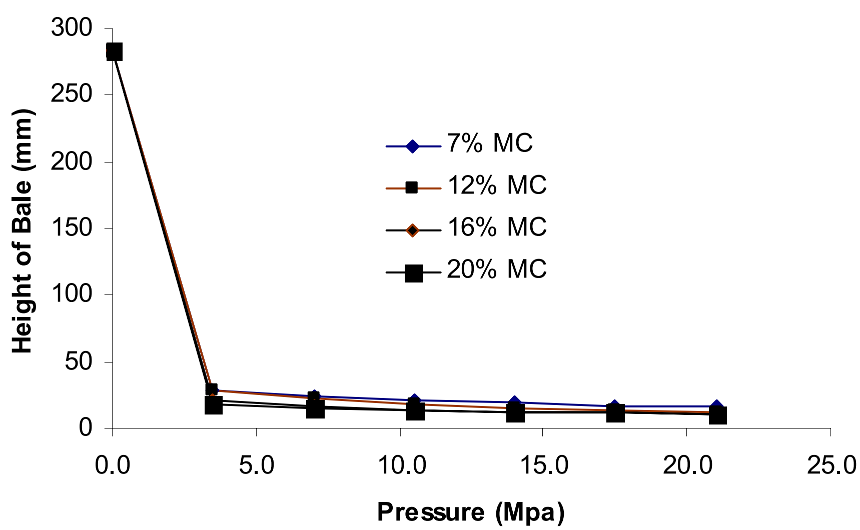

Fig. 2. The changes in bale thickness with applied load.

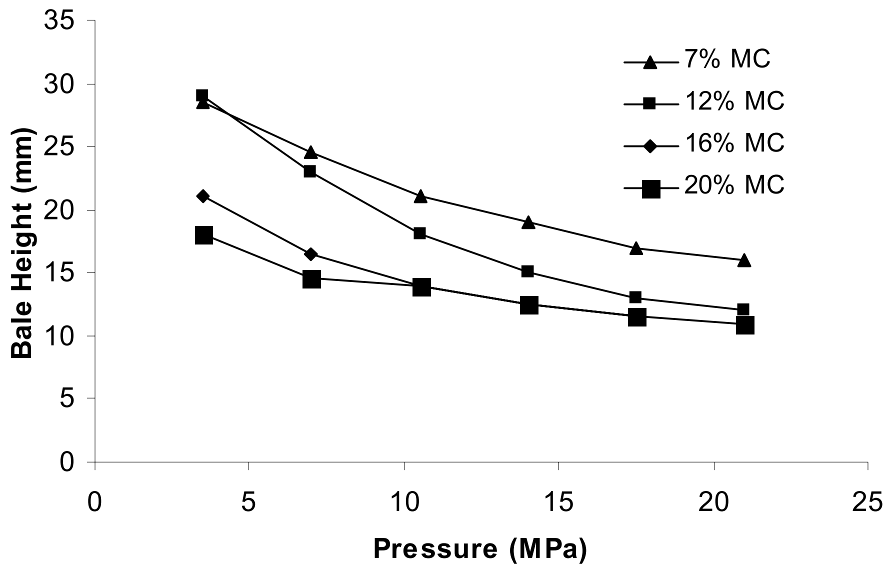

Fig. 3. The changes in thickness of the bale from 3.5 MPa to 21 MPa pressure..

The data for changes in density of the bales under different pressure and moisture content are presented in Table II. The plot of variations in the densities of the bales is presented in Figure 4. It is clear that the density of the bales increases with the applied pressure and the bales with higher moisture content initially have higher density. However, the 16 and 20% moisture content hays reach the same density at 10.5 MPa. This is due to their original equal weights and final equal thicknesses as indicated in Table I. It is interesting to notice that the 12% moisture content hay, after about 7.0 MPa, exhibits an increase in its density. The densities follow the same trends as the thickness of the bales, but in opposite manner.

Table II. Densities of the bales at different pressures and moisture contents.

Pressure (Mpa)	Moisture Content			
	7%	12%	16%	20%
0.0	45.1	45.1	45.1	45.1
3.5	449.1	441.4	609.5	711.1
7.0	522.4	556.5	775.8	882.8
10.5	609.5	711.1	914.3	914.3
14.0	673.7	853.3	1024.0	1024.0
17.5	752.9	984.6	1113.0	1113.0
21.0	800.0	1066.7	1163.6	1163.6

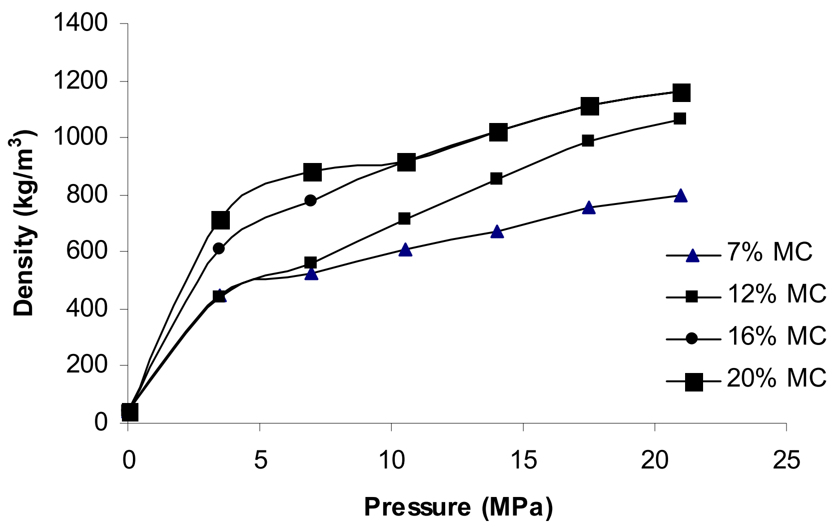

Fig. 4. The change in densities of the bales as pressure is increased.

After leaving the bales to equilibrate with the surrounding moisture for about 15 days, all the bales reached a moisture content of 7%. Assuming retaining their original volumes (strapped bales), their density must decreases due to the loss of moisture. The results of calculated changes in densities due to loss of moisture are given in Table III and the same data are plotted in figure 4.

Table III. Change in density of the bales after drying.

	Density (kg/m^3)	
Moisture Content (%)	Before Drying	After Drying
7	800	800
12	1066	1013
16	1163	1058
20	1163	1024

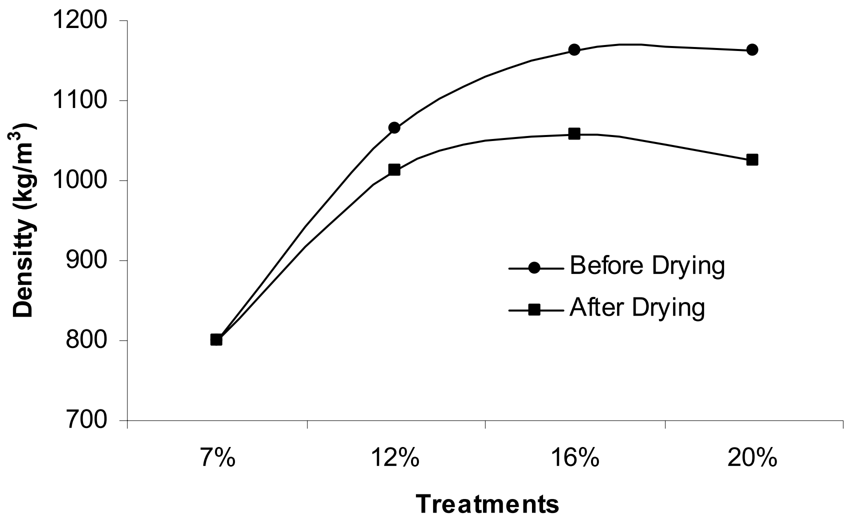

Fig. 5. The trend in changes of the volume of the bales at initial moisture content and after being dries.

The graph shows that with increase in moisture content, the density initially rises exponentially and then it levels off. However after drying, the density of the bales decreases. The densities of the bales after drying increase as their original moisture content increases. Then the density decrease from a moisture content of about 16% wb. Thus, baling hays at 16% moisture content will result in higher final bale density and consequently lower volumes.

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