Power requirements and bale characteristics for a fixed and a variable chamber baler

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Tremblay, D., Savoie, P. and LePhat, Q. 1997. Power requirements and bale characteristics for a fixed and a variable chamber baler. Can. Agric. Eng. 39:073-076. A variable-chamber baler (VCB) and a fixed-chamber baler (FCB) were compared with respect to power requirements, field capacity, and bale mass. The fixed-chamber baler was operated with and without a coarse cutting mechanism (FCB/C and FCB, respectively). Average PTO power requirements were similar (10 to 15 kW) but peak power requirements were considerably greater with the FCB (38 kW) and the FCB/C (42 kW) than with the VCB (15 kW). The VCB had a material flow of 4.1 tonnes of dry matter (DM) per hour (t/h) compared to 4.8 and 4.6 t/h with the FCB and FCB/C respectively. Bale dry matter mass was not affected by baler type nor by cutting and averaged 263 kg for a standard 1.22 m wide by 1.22 m diameter bale. Bale dry matter density varied, however, between 152 and 192 kg/m3 because of variations in material flow and moisture. Forage chopped with the FCB/C had an average length of cut of 150 mm. Keywords: forage, round bales, power, mass, density, chop length.

INTRODUCTION

Round balers were introduced in the 1970’s to facilitate handling of large quantities of field-dried hay (Renoll et al. 1978). The round baler has also proven to be a convenient and economical alternative to chopped forage for silage making (Kjelgaard et al. 1981; Harrison 1985). Several manufacturers modified their round balers to meet some of the new requirements associated with handling wet windrows and heavy bales. The Prairie Agricultural Machinery Institute published 24 reports on as many different commercial round balers between 1977 and 1992 (PAMI 1992), illustrating some of the rapid changes in round baler equipment.

A survey of new commercial balers available in the province of Québec (Canada) in 1991 revealed that there were 56 round baler models distributed under 13 brand names (MAPA 1992). Of these, only five were among the 24 models tested by PAMI (1992). The above data indicate how difficult it is to keep track of all the new technology.

Freeland and Bledsoe (1988) reported that balers with fixed-geometry chambers required larger tractors than balers with variable-geometry chambers. They tested six round balers in either grass or alfalfa crops harvested at moisture ranging between 21 and 38% on a wet basis (w.b.). This range does not cover the typical round bale silage moisture range (40 to 70% w.b.).

The objective of this experiment was to compare a FCB with a VCB according to power requirements, field capacity, and bale mass and density. A commercial model of each machine was selected to harvest windrows at moisture contents in the range of 20 to 75% (w.b.).

PROCEDURE

Baler description

The FCB used was a Welger RP200 model with bale diameter of 1.25 m and width of 1.22 m (Trade names are used solely to provide specific information. Mention of trade names does not constitute an endorsement of the product to the exclusion of other products not mentioned). The windrow pickup width was 2.00 m. The forage chopping mechanism on the FCB was a series of 14 static knives spaced 82 mm apart and installed vertically behind the windrow pickup. When the cutting mechanism was activated (FCB/C), forage was pulled through the 14 knives before reaching the bale formation chamber. The set of knives could be pulled down and therefore inactivated, representing the conventional method of moving full-length forage directly into the bale chamber (FCB). The baler was operated at 540 rpm. Chamber pressure was set at the maximum level for haylage and silage and at the level just below maximum pressure for hay.
The VCB was a Gehl RB1470 model with maximum bale diameter of 1.52 m and width of 1.14 m. The actual diameter was set at 1.22 m and the windrow pickup width was 1.40 m. Two pressures were exerted sequentially against the bale in the variable-geometry chamber: a pneumatic pressure of 0.8 MPa to form the core, and a hydraulic pressure through a series of belts to maintain the bale under tension. The hydraulic pressure could range between 0.5 and 3.3 MPa and the manufacturer’s recommended pressure of 2.6 MPa was used. For high-moisture bales (moisture 50-75%, w.b.), the core diameter was set at 0.33 m. For dry bales (moisture around 20%, w.b.), the core diameter was set at 0.69 m. The VCB was operated at 450 rpm and it did not contain a chopping mechanism option.

Experimental design
Both balers were used on a commercial farm in Saint-Stanislas (QC) near the Normandin Experimental Farm (48°50’ N; 72°31’ W) during first cutting of grass between June 29 and July 3, 1992. Grass, mainly timothy and bluegrass, was at the boot and early heading stage, with a yield of 1.35 t/ha of dry matter. A 3x3 factorial experimental design was used with three machine treatments: VCB, FCB, and FCB/C and three target moisture levels: 75% moisture (wet silage), 50% moisture (haylage), and 20% moisture (hay). The grass was mowed using a conventional mower-conditioner. Silage and haylage treatments were harvested approximately after a wilting period of 4 h and 24 h, respectively. The hay was harvested third when there were two successive sunny days at the end of the week.

Measurements during baling
Two main measurements were taken during baling: material flow and power requirements. Material flow was obtained by measuring bale formation time in the chamber, tying time, and ejection time from the chamber to the field. Power requirement was measured continuously at a 10Hz frequency by a torque meter attached to the tractor’s PTO shaft (Tremblay et al. 1994). Mean power is the average during bale formation; peak power is a 1-s average of 10 measurements. Power was measured at running speed for 20 s (zero-flow) and during the complete cycle (bale formation, tying, ejection). A total of 43 bales (4 or 5 bales for each of 9 treatment combinations) was harvested for material flow and power measurements.

Bale physical characteristics
An additional 114 bales (between 10 and 15 per treatment combination) were harvested for bale characteristics evaluation. Each bale was weighed on a flat scale (Weigh-Tronix DSL) with a capacity of 1000 kg and a resolution of ±0.2 kg. Two measures of circumference and width provided the dimensions to estimate volume. Three random forage samples totalling 500 g were hand-collected in the windrow just in front of the baler and oven-dried at 60°C for 72 h to estimate the moisture at baling (ASAE 1993a).

For FCB/C, samples were taken to measure the actual length of cut. This was done by unrolling each bale from the power measurement trials (15 in total) and taking a 1-kg sample that was immediately frozen. The unchopped forage height was obtained by taking samples of the wilted crop in the windrow prior to baling and freezing them. After all samples were subsequently thawed, the mean length of cut was estimated according to a standard method (ASAE 1993b).

RESULTS AND DISCUSSION
Power requirements
At running speed under zero forage flow, the PTO power requirement was 3.2 kW for VCB and 1.0 kW for FCB. The moving belts in the VCB caused more friction at zero-flow than the rotating rolls in the FCB.

Table I summarizes power measurements with the nine treatments as forage was picked up and compressed in the bale chamber. Values are averages for 4 or 5 bales per treatment. There were small but significant differences (p=0.05) in the mean PTO power requirements between the VCB (10.2 kW) and the FCB (13.3 kW) or FCB/C (14.5 kW). The additional 1.2 kW of average power required for cutting was not significant by Duncan’s multiple range test (MRT) at p=0.05. The VCB had a peak power requirement of 14.5 kW while the FCB and FCB/C had peak requirements of 37.5 and 42.2 kW, respectively. The differences between the three machines were significant at p=0.05 by Duncan’s MRT.

Typical time related curves of power during bale formation are illustrated in Figs. 1 and 2. A relatively uniform requirement of 10 to 15 kW was observed with the VCB (Fig. 1). In contrast, the power requirement increased gradually up

<table>
<thead>
<tr>
<th>Chamber type</th>
<th>Conservation mode</th>
<th>PTO power§ (kW)</th>
<th>Material flow§ (t DM/h)</th>
<th>Field capacity† (t DM/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Peak</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>Hay</td>
<td>8.5</td>
<td>12.1</td>
<td>5.55</td>
</tr>
<tr>
<td></td>
<td>Haylage</td>
<td>11.1</td>
<td>15.8</td>
<td>3.88</td>
</tr>
<tr>
<td></td>
<td>Silage</td>
<td>11.2</td>
<td>16.0</td>
<td>4.39</td>
</tr>
<tr>
<td>Fixed</td>
<td>Hat</td>
<td>14.3</td>
<td>40.7</td>
<td>8.51</td>
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<td>3.82</td>
</tr>
<tr>
<td></td>
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<td>13.7</td>
<td>38.6</td>
<td>5.66</td>
</tr>
<tr>
<td>Fixed with</td>
<td>Hay</td>
<td>16.5</td>
<td>44.6</td>
<td>7.78</td>
</tr>
<tr>
<td>knives</td>
<td>Haylage</td>
<td>12.2</td>
<td>39.3</td>
<td>3.76</td>
</tr>
<tr>
<td></td>
<td>Silage</td>
<td>14.8</td>
<td>42.8</td>
<td>5.63</td>
</tr>
</tbody>
</table>

§ based on data recording during bale formation.
† based on bale mass and baling, tying, and ejection time.
Table II: Average moisture content, bale DM mass, and bale DM density of each treatment

<table>
<thead>
<tr>
<th>Chamber type</th>
<th>Conservation mode</th>
<th>Moisture content (%)</th>
<th>Bale mass (kg DM)</th>
<th>Volume (m³)</th>
<th>Density (kg DM/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Hay</td>
<td>16.4</td>
<td>265.4</td>
<td>1.61</td>
<td>164.8</td>
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<tr>
<td></td>
<td>Haylage</td>
<td>55.9</td>
<td>260.9</td>
<td>1.56</td>
<td>167.2</td>
</tr>
<tr>
<td></td>
<td>Silage</td>
<td>63.8</td>
<td>251.8</td>
<td>1.63</td>
<td>154.5</td>
</tr>
<tr>
<td>Fixed with</td>
<td>Hay</td>
<td>16.4</td>
<td>265.4</td>
<td>1.61</td>
<td>164.8</td>
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<tr>
<td></td>
<td>Haylage</td>
<td>55.9</td>
<td>260.9</td>
<td>1.56</td>
<td>167.2</td>
</tr>
<tr>
<td></td>
<td>Silage</td>
<td>64.8</td>
<td>236.1</td>
<td>1.60</td>
<td>147.6</td>
</tr>
<tr>
<td>Variable</td>
<td>Hay</td>
<td>16.7</td>
<td>238.5</td>
<td>1.57</td>
<td>151.9</td>
</tr>
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<td>Haylage</td>
<td>52.9</td>
<td>295.8</td>
<td>1.58</td>
<td>187.2</td>
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<tr>
<td></td>
<td>Silage</td>
<td>62.2</td>
<td>272.0</td>
<td>1.67</td>
<td>162.9</td>
</tr>
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</table>

to 35 kW for FCB (Fig. 2). The curves obtained for both baler types corresponded well to the general curves presented by Freeland and Bledsoe (1988). The FCB would require a considerably larger tractor than the VCB because of the high power exerted to complete bale formation just before tying and ejection.

Material flow

Averaged across moisture, material flow during bale formation was 4.61 t DM/h for VCB, 6.00 t DM/h for FCB, and 5.72 t DM/h for FCB/C (Table I). The actual field capacities, which include tying and ejection times, were 3.8, 4.3, and 4.2 t DM/h, respectively. Because the FCB had a wider pickup (2.0 m vs 1.4 m) and faster turning PTO (540 rpm vs 450 rpm), it could move faster in the field than the VCB which was especially useful in low yield.

The hay crop was systematically harvested at a higher field capacity (5.0 t DM/h) than silage (4.1 t DM/h) or haylage (3.3 t DM/h). This was because hay windrows were generally tripled before baling while silage and haylage windrows were baled singly. Haylage plots corresponded to the lowest yields; baler feeding capacity was therefore limited by soil topography and forward speed rather than machine type or moisture.

Bale mass and density

Table II shows the moisture content, mass, volume, and density for the nine treatment combinations. Values are averaged over 15 to 20 bales per treatment, a combination of bales from the power and field capacity trials. The three target moisture levels (20, 50, and 75%) are identified by the conservation mode: hay, haylage, and silage, respectively. The actual average moisture contents were 17.8, 54.7, and 63.6%, respectively. Although bale mass ranged between 236 and 301 kg DM, there was no significant difference (p=0.65) between bale type: the average mass per bale was 266, 262, and 259 kg DM for the VCB, FCB, and FCB/C, respectively. The cutting mechanism did not have any effect on bale mass, probably due to the relatively coarse chopping.
Moisture caused significant differences \((p=0.0001)\) in bale DM mass with an interaction \((p=0.0001)\) due to machinery type. Overall, haylage bales contained more dry matter \((286 \text{ kg DM})\) on average than wetter silage bales \((253 \text{ kg DM})\) or drier hay bales \((252 \text{ kg DM})\). Considering only the VCB and FCB without the cutting mechanism, haylage bales were considerably heavier \((297 \text{ kg DM})\) than average silage \((254 \text{ kg DM})\) or hay bales \((245 \text{ kg DM})\). In the case of FCB/C, Le. with the cutting mechanism, haylage bales were not heavier \((261 \text{ kg DM})\) than silage \((252 \text{ kg DM})\) or hay bales \((265 \text{ kg DM})\). It should be pointed out that haylage was generally harvested at a slower material flow rate, which provided more time to increase compactness during bale formation. As a result, haylage bales were denser \((182 \text{ kg DM/m}^3)\) than silage bales \((155 \text{ kg DM/m}^3)\) and hay bales \((158 \text{ kg DM/m}^3)\). However, the baler type did not significantly affect bale densities which were 167, 166, and 162 kg DM/m\(^3\) for VCB, FCB, and FCB/C, respectively.

**Chopped bale particle length**

The forage was chopped coarsely with the FCB/C. The fresh crop itself was relatively short \((298 \text{ mm on average})\). The mean particle lengths \((\text{MPL})\) were 145, 135, and 162 mm for hay, haylage, and silage, respectively. The non-dimensional geometric standard deviations calculated according to ASAE \((1993b)\) were 2.1, 2.1, and 1.9, respectively. These results show that the cutting mechanism chopped stems in only two or three pieces which was insufficient to affect bale dry matter density.

Power and throughput measurements were made under actual commercial harvest conditions to compare performance of three baler configurations at three moisture levels. Other factors such as yield, windrow handling prior to baling, and material throughput during baling could be significant factors. Further research on the effect of these factors on power and throughput is required for a more complete understanding of round baler performance.

**CONCLUSIONS**

1. The variable-chamber baler \((\text{VCB})\), the fixed-chamber baler \((\text{FCB})\), and the FCB with a coarse cutting mechanism \((\text{FCB/C})\) used in this experiment required an average PTO power of 10.2, 13.3, and 14.5 kW, respectively. However, the peak PTO power required was considerably lower for VCB \((14.5 \text{ kW})\) compared to FCB \((37.5 \text{ kW})\) and FCB/C \((42.2 \text{ kW})\). A larger tractor would normally be required to operate the FCB and the FCB/C.

2. Bales of standard dimensions \((1.22 \text{ m wide by } 1.22 \text{ m diameter})\) weighed between 236 and 301 kg DM, with an average of 263 kg DM. Bale density varied between 152 and 192 kg DM/m\(^3\). Bale DM mass and bale density were not influenced by baler type but they varied with forage moisture.

3. A series of 14 static knives on the FCB/C provided coarse chopping with average cut pieces ranging between 135 and 162 mm in length. The cutting mechanism required slightly more average power but it did not increase bale mass or density.

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**REFERENCES**


