INVESTIGATION INTO FILM CONSUMPTION FOR SEALING SQUARE SILAGE BALES

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Abstract. Green forage mass (haylage) treatment in a pressed way with subsequent sealing in a flexible film ribbon has been developing in the Baltic States and Poland for approximately 15 years, and presently it occupies an important position among the ways of forage preparation. A shortcoming of this technology is the high cost of the film. There are factors investigated affecting the film consumption for sealing square bales and a comparative estimation is conducted of the estimated and experimental data.

Key words: square bale wrapper, baling and wrapping, film consumption.

Introduction

The technology of processing stalked crops in rolls with subsequent sealing in a flexible film has initiated stormy development in the world during the last 10-15 years – after adaptation of this technology to the processing of the green forage mass (haylage).

The technology of haylage processing in rolls with subsequent sealing in a film is the following. It is desirable to wilt the grass cut at an early stage of vegetation which is rich in proteins, vitamins and other valuable nutrients to 55-65 % moisture. When the forage is harvested by baling presses, it is necessary to make rolls of high density (using baling presses with disintegration of the grass the pressing density may reach 600-800 $kg \cdot m^{-3}$). After that, to prevent access of air, moisture and light, the rolls are sealed for 2-4 hours (depending on the air temperature) by means of special wrappers using a ribbon-like flexible adhesive film of a non-transparent colour or special flexible polyethylene pipes.

Wrapping of the rolls in a ribbon-like film takes place in 2-3 layers. The small amount of air which exists in the roll creates short-term conditions for light lactic acid fermentation, and then the developed carbonic acid gas ensures a self-conservation process. Since the access of oxygen is interrupted, the development of mould stops. In case the rolls are transported later to storehouses, precautionary measures should be taken in order to avoid depressurising of the rolls. Feeding the prepared forage to animals can start in 6 weeks when all the biological processes of fermentation have ceased. It is desirable to feed out the opened roll in 20-30 hours. The forage stored in the roll preserves its nutritive qualities up to 2 years.

In Latvia and Poland such technology is mainly applied to treat cylindrical rolls. For the time being, the big size bales are used for this purpose to a limited extent, and, on the whole, a more detailed study of the factors is needed which affect the economic indices. The issues concerning the impact of individual parameters of the machines and other factors on the film consumption for sealing cylindrical rolls has been discussed in a series of scientific papers [1; 5; 6].

Materials and methods

The tasks of the investigations were a theoretical estimation of the film consumption for wrapping square bales, revealing the basic factors which affect it, as well as their comparison with the experimental data. An experimental estimation of the film consumption was conducted on the basis of the standard PN-90/R-55003, BN-76/9195-01, BN-77/9195-02 (Poland) and was determined by dividing the mass (or the area) of a standard roll of the film, 75 or 50 cm wide, by the number of sealed bales [2; 3; 4]. Conformity with the data obtained in this way was checked also in winter after the film was removed from the bales before feeding out.

Fig. 1 shows a wrapper of square bales with a film ribbon which has a rotary table (A) and a rotary film carrier (B).

a)  b) 

Fig. 1. **Wrapping of a square bale with a film ribbon**

Results and discussion

The most important advantages of the green forage processing technology in rolls with subsequent sealing in a flexible film under the conditions of the Baltic States and Poland are [1]:

- a significantly lesser degree of dependence of forage processing on the weather conditions, complete mechanisation of the technological processes;
- no special storage facilities (barns, trenches) are needed for the forage;
- increased nutritive value and good gustatory qualities of forage enabling essential increase in the yields of milk and its quality (conservation of all nutrients and vitamins), insignificant losses of nutrients (not more than 10-15 %) during harvesting and storage;
- ecological safety of the technology (elimination of environmental pollution by silage saps, absence of compounds that are harmful for the body of the animal and that arise in conventional siloing, low acidity). No artificial preservatives are used.

The main problematic factors for the propagation of the present technology are the high cost of the machines for baling, wrapping and a particularly great share of expenditure for the acquisition of the film – up to 35-48 % of all the maintenance costs.

In our previous investigations [1; 5; 7] we discussed a wrapping process of cylindrical rolls with a film and studied the factors affecting the film consumption. In a technological aspect wrapping of single bales with a film is an overlaying process of the film ribbons so that they overlap, and, in principle, it is similar to the wrapping process of the rolls, the basic differences being in the geometrical form of the sealed objects. In contrast to the rolls, simulation of the film consumption for wrapping the rolls is more complicated because of the great number of parameters that characterise its amount. Fig. 2 shows a scheme of overlaying the film ribbons during the wrapping of the square bale.

The theoretical consumption of the film (m^2) for wrapping a single forage bale can be expressed by the following equation:

$$Z_{ppb} = \frac{2(B+H)b}{(b-c)}(D_{śr}+L), \quad (1)$$

where B –width of the bale, m;
H – height of the bale, m;
L – length of the bale, m;
$D_{śr}$ – equivalent diameter of the bale, m;
b – width of the film ribbon, m;
c – value of overlapping (overlaying) of the adjacent layers of the film, m;
i – number of the layers of the film.

Application of the relative parameter "the equivalent diameter of the bale" in the research can be explained by the need to use a comparative analogy with the rolls in the future. The equivalent diameter of a bale $D_{śr}$ can be calculated according to the formula:

$$D_{\acute{s}r} = \frac{4B + 4H + 3\sqrt{B^2 + H^2}}{11}. \tag{2}$$

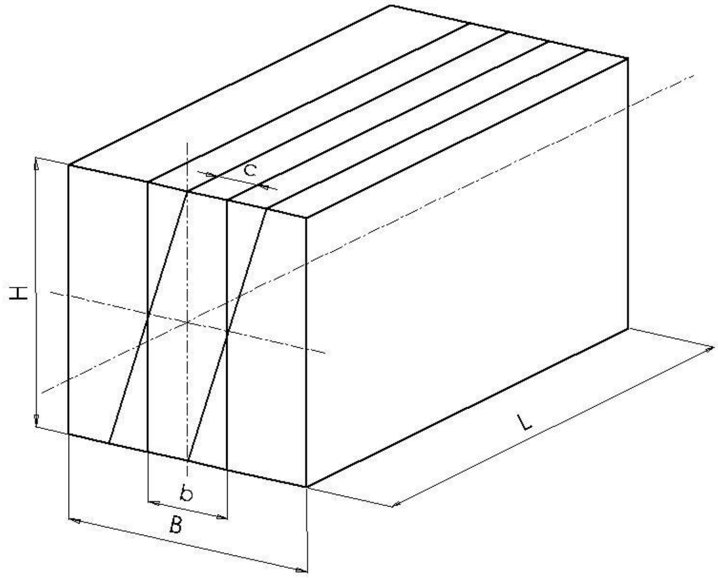

Fig. 2. **A scheme of overlaying the film ribbons during wrapping of the square bale**

The overlapping coefficient λ of the layers of the film can be presented as a ratio between the width of the overlapping area and the width of the film ribbon, and is connected with the turning angle of the bale around the longitudinal axis during one revolution of the wrapper:

$$\lambda = \frac{c}{b}. \tag{3}$$

Inserting the value c from formula (3) into formula (1) we obtain

$$Z_{cpb} = \frac{\pi D b}{(b-c)}(D+L) = \frac{\pi D b}{b(1-\lambda)}(D+L) = \frac{\pi D(D+L)}{1-\lambda}\ . \tag{4}$$

The number i_1 of the overlaid layers of the film for one first full wrapping of a bale with a film is equal to:

$$\frac{1}{1-\lambda} = i_1. \tag{5}$$

Depending on the kinematic parameters of the wrappers there are several systems of wrapping differing mainly in the value of the overlapping coefficient λ. In the most popular wrapping system "2 x 2" the coefficient $\lambda = 0.5$, i.e., overlapping of the adjacent layers constitutes a half of the width of the film, and the bale is covered with two layers of the film during a single turn around its longitudinal axis. Since the technological process requires not less than 4 layers of the film by its thickness, for the wrapping scheme "2 x 2" the total number of the overlaid layers of the film $i = 2i_1$ but for 6 layers – $i = 3i_1$, i.e., the number of the overlaid layers of the film is twice as great as the number of revolutions of the bale around its longitudinal axis).

After inserting the value (5) into formula (4) we obtain

$$Z_{ppb} = \frac{2(B+H)}{(1-\lambda)}(D_{\acute{s}r} + L) = 2(B+H)(D_{\acute{s}r} + L)i\ . \tag{6}$$

The film consumption Z_{ppv} ($m^2\ m_h^{-3}$ – square meters of film to the winding of one cubic meter of haylage) per unit of the forage in the bale will be:

$$Z_{ppv} = \frac{2\cdot(B+H)\cdot(D_{\acute{s}r} + L)\cdot i}{B\cdot H\cdot L}\ . \tag{7}$$

The film consumption Z_{ppm} (m^2 t$_{c.m}^{-1}$.) per unit of the dry substance mass in the bale:

$$Z_{ppm} = \frac{2 \cdot (D_{sr} + H) \cdot (D_{\acute{s}r} + L) \cdot i}{\gamma_p \cdot B \cdot H \cdot L} , \tag{8}$$

where γ_p – density of haylage per unit of the amount of the dry substance in the bale, $t_{c.m.} \cdot m_h^{-3}$.

As it is evident from the obtained relationships, the width of the film does not affect the value of its consumption when single bales are sealed. The popular variants of the width of the film 0.75 m or 0.50 m exert an effect only on the speed or efficiency of the wrapping process, yet it has a directly proportional impact on the necessary number of revolutions of the wrapper table and, consequently, the efficiency of the operation. Thus, when a 0.75 m film is used instead of the film which is 0.50 m wide, its consumption for wrapping one bale decreases approximately by 40-45 %.

The consumption of the film depends on the density of the forage in the bale, the geometric dimensions of the bale and the number of the overlaid layers of the film. The number of the layers of the film is determined by technological requirements (to prevent the access of air), and it is generally not less than four. If the density of the forage in the bale increases, the consumption of the sealing film decreases in direct proportion [8]. The density of the forage in the bale depends on the design of the balers and their mode of operation. In addition to it, there is a practical compression limit of the grass mass in the bale; for instance, it is practically impossible to achieve a density over 850-900 kg·m^{-3}. Increasing the geometric dimensions of the bales allows a decrease in the consumption of the film; however, this effect is not so significant in comparison with the increase in the baling density.

If the geometric dimensions of the bales increase, the consumption of the film per unit of the mass decreases. The cross section of the baling chamber (consequently, the cross section dimensions of the bale) depends on the design and is a constant value for the particular baler but the length of the bale to be formed is in many cases adjustable. For this technology the limiting factor of the length of the bale is the ultimate length of the wrapper platform.

The highest consumption of the film takes place when bales are used of 0.8x0.7 m dimensions, and it constitutes 190.2-228.4 m^2·t^{-1} of the dry mass, but the lowest 154.1-191.4 m^2·t^{-1} of the dry mass – when bales are used with the cross section dimensions of 0.9x1.2 m.

Fig. 3 shows the values of the film consumption in four and in six layers for the bales having the dimensions B = 1.2 m x H = 0.7 m and the length L = 1.6 m for the wrapper variant of a single (n = 1) bale and a double (n = 2) bale. Application of double bales for wrapping allows reduction of the film consumption only by 25.2 %, which confirms the expediency of the often practised variant when double bales are wrapped [9].

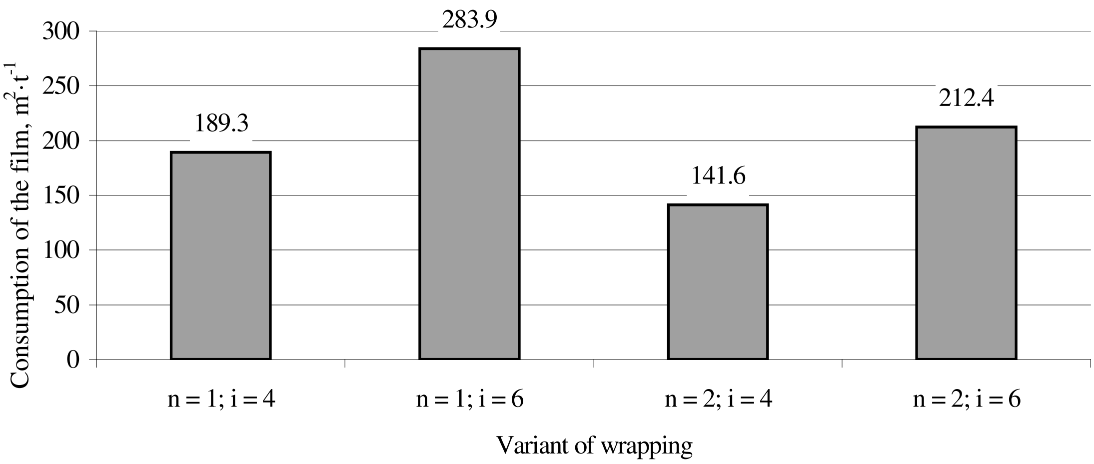

Fig. 3. **Consumption of the film for wrapping bales (m^2·t^{-1} for the dry mass of the forage) with a different number of layers (*i*) for the wrapping variant of a single (*n* = 1) bale and of a double bale (*n* = 2)**

In practice, when the mass of the film used for wrapping a single roll is determined, there are slight fluctuations in the values caused by certain variations in the geometric dimensions and other factors. Thus, it was found out during the experiments that the average mass of the film used for sealing square bales with the dimensions 1.2 m x 0.7 m x 2.3 m was 1.39 kg (the maximum value being 1.48 kg and the minimum value – 1.33 kg).

The data from the comparison of the theoretical and the experimental consumption rate of the film are presented in Table 1.

Table 1

Comparative indices of the experimental and the estimated consumption rate of the sealing film

Indices	Sealing of	
	bales	**rolls**
Experimental consumption rate of the film, kg	1.29	0.84
Theoretical (estimated) consumption rate of the film, kg	1.18	0.83
Difference between the estimated and the experimental consumption rates of the film, %	8.5	2.2

On the whole, the proposed dependencies for the calculation of the film consumed in order to seal single bales and rolls allow quite precise estimation of the final result and evaluation of the impact of individual parameters on it. More essential disagreement between the theoretical and experimental consumption of the film for the square bales (8.5 %), in contrast to the rolls (2.2 %), may be determined by the fact that different stretching rates of the film at the corners of the square bale were taken into consideration.

A comparison of the experimental data about the consumption of the film per 1 ton of the dry mass for the most common standard sizes of bales and rolls in Poland and Latvia is shown in Fig. 4. The specific film consumption for wrapping the rolls is by 21 % lower than for the bales.

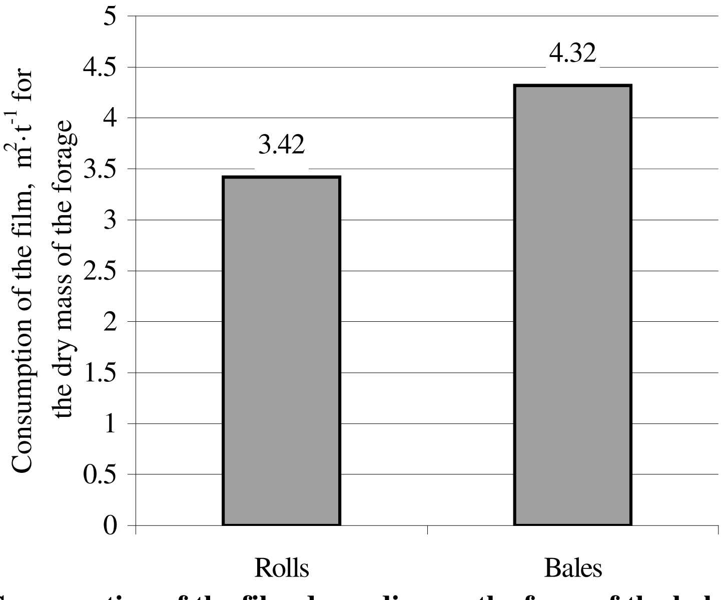

Fig. 4. **Consumption of the film depending on the form of the baled forage (rolls: *D* = 1.2 m, *L* = 1.2 m; bales: *B* = 1.2 m, *H* = 0.7 m, *L* = 1.6 m)**

Conclusions

1. The width of the film used for sealing forage does not affect its consumption. In contrast to the film which is 0.5 m wide, application of a film which is 0.75 m wide raises the efficiency of the wrapping process up to 45 %.
2. The most important factor having impact on the specific consumption of the film (per unit of the forage mass) is the baling density of forage. Increasing the geometric dimensions of the bales

allows a decrease in the consumption of the film; however, this effect is not so significant in comparison with the increase in the baling density.
3. The estimated values of the film consumption are close to the experimental ones (deviation not more than 10 %).
4. The experimental data about the consumption of the film per 1 ton of the dry mass for the most common standard sizes of bales and rolls in Poland and Latvia have shown that the specific film consumption for wrapping the rolls is by 21 % lower than for the bales.

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