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Impact of the parameters of round and square haylage bales on the consumption of the sealing film for individual and in-line wrapping

S. Ivanovs[1,*], S. Gach[2], I. Skonieczny[2] and A. Adamovičs[1]

[1]Latvia University of Agriculture, Research Institute of Agricultural Machinery, 1 Institute Str., Stopini reg., Ulbroka, Latvia;
[*]Correspondence: semjons@apollo.lv
[2]Warsaw Agricultural University, Nowoursynowska 166 St. 02-787 Warsaw, Poland

Abstract. In the Baltic States and Poland haylage processing in a baled form with subsequent sealing in a flexible film has been intensively applied for about 15 years, and now it occupies an important place among the forage processing methods. A drawback of this technology is the high cost of the film. There are factors investigated having impact on the cost of the film used for sealing individual round and square (rectangular) bales separately and in a long line. Comparative estimation has been made of the design values and the experimental data. For both variants, the size of the bales being equal, lesser consumption (approximately by 8%) of the film will be when the bales are sealed (wrapped). In contrast to individual wrapping of each bale, in-line wrapping of bales reduces the consumption of the film by two times.

Key words: round or square bales, baling and wrapping, in-line bale wrapper.

INTRODUCTION

In the Baltic States and Poland haylage processing in a baled form with subsequent sealing in a flexible film has been intensively applied for about 15 years, and now it occupies an important place among the forage processing methods (Ivanovs, 2005). There are several methods of wrapping round and square bales in a ribbon-like film, including individual wrapping of the round bales according to the 'conventional' scheme, individual wrapping of the round bales according to System NHK 3D (Nowak, 2001), and wrapping of a group of round or square bales lying in a long line (in-line wrapping) (Besozzi & Pignedoli, 2006; Gach et al., 2008). The most widespread material for wrapping is a ribbon of film wound in rolls, 50 or 75 cm wide, but for the small size round bales also a 25 cm wide film is used. The most popular way of wrapping in the Baltic States and Poland is individual wrapping of cylindrical bales (Olszewski, 2001; Olt & Jurs, 2002; Ivanovs, 2005; Gach, 2007). For the time being the big square bales have found much less application (Gach, 2008). An obvious drawback of individual wrapping of the round or square bales is the great consumption of film, which constitutes about 40–60% of all the operating costs (Olszewski, 2001; Ivanovs, 2005). Sealing of a group of round or square bales arranged in a long line (generally, about 60 m) has started only recently on large agricultural farms. An advantage of this variant is reduced consumption of film but its shortcoming – more complicated organisation of the processing and utilisation process (particularly in small holdings). The impact of individual factors upon the consumption of the film for sealing round bales has been studied in a series of scientific papers (O'Kiely, 2000; Ivanovs, 2005); however this issue remains topical and needs further comparative studies.

MATERIALS AND METHODS

The task of these investigations was theoretical determination of the correlation between the consumption of a ribbon-like film and the basic parameters of the round and square bales using the in-line and the individual methods of wrapping. The need to understand analytical relationships and to obtain calculation data on their basis can be explained also by the fact that under experimental conditions it is possible to compare not more than 2–3 variants or parameters (for instance, the cross-sectional dimensions of the bales), which requires great expenditure; nevertheless full regularity will not show up. On the basis of the data about the consumption of the film it may be possible to estimate the economic indicators and choose optimal forage processing technologies and parameters of the machines for particular farming conditions (Skonieczny, 2009). In order to solve this task, schemes for overlaying the film were drawn up, and, after applying several mathematical operations, analytical relationships were obtained.

Fig. 1 shows machines for the in-line wrapping of a group of round and square bales in a ribbon-like film.

a) 

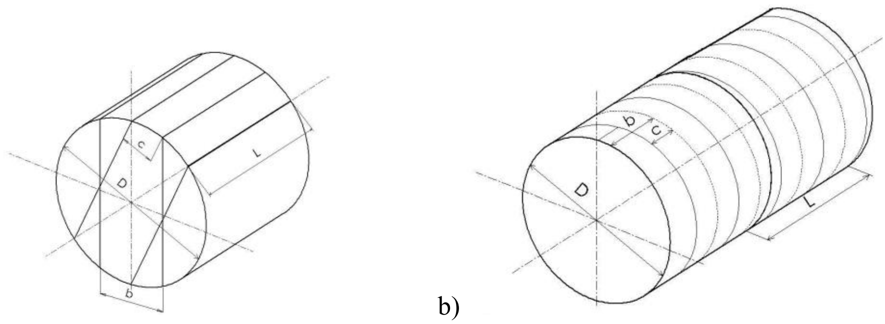
b) 

Figure 1. Machines for the in-line wrapping of a group of round bales (a) and square bales (b) in a ribbon-like film.

Fig. 2 and 3 show the calculated schemes for overlaying the layers of film for individual and in-line wrapping of a group of round and square bales.

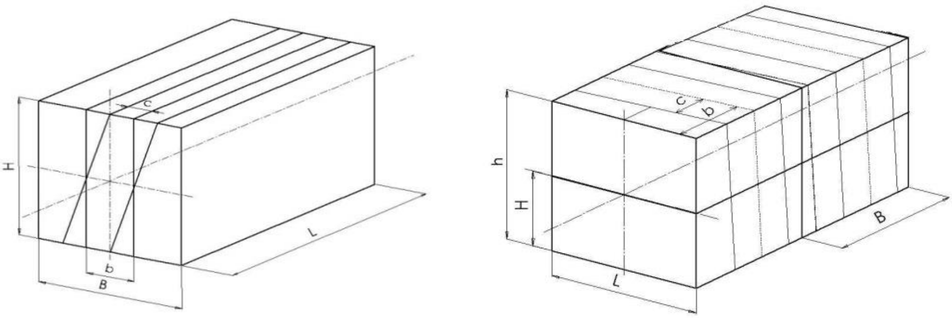
Designations in the schemes and formulae: D – the diameter of a round bale, m; L – the length of a round and square bale, m; B – the width of a square bale, m; H – the height of a square bale, m; b – the real width of the film, m; c – the width of the overlap, m; i – the number of the applied layers of the film (determined by the technological requirements, and in all the compared variants it must be the same. As a rule, wrapping is carried out with not more than two full layers of the film (McEniry, 2011); n – the number of the wrapped bales; h- the height of two bales (a variant, found in practice, of wrapping a group of bales when they are laid with the long side perpendicular to the line of the row, and in two layers, m).

Technologically wrapping of individual round or square bales in the film is a process of overlaying the ribbons of the film which overlap the bale rotating around its axis. Besides, in each complete turn the film passes through the middle of the end face of the round or square bale (as a result, many times during the entire cycle). Wrapping of a group of round or square bales arranged in a long line can be treated in a simplified way as helical overlaying of the ribbon on a rod. In comparison with the round bales, simulation of the consumption of the film for wrapping the square bales is a little more complicated due to the great number of parameters that characterise their dimensions.



a) b)

Figure 2. A scheme of overlaying the ribbons of the film for wrapping round bales: a) – individual wrapping of each bale; b) – in-line wrapping of a group of bales.



c) d)

Figure 3. A scheme of overlaying the layers of the film for wrapping the square bales: c – individual wrapping of each bale; d – in-line wrapping of a group of bales.

In order to make a comparative estimation of the variants, it is expedient to determine the value of the specific consumption of film which may be expressed: 1) in the units of the area of the film per unit of the mass of forage, or per unit of the volume of forage ($m^2\ kg^{-1}$, $m^2\ m^{-3}$); or 2) in the units of the mass of the film per unit of the mass or volume of forage ($kg\ kg^{-1}$, $kg\ m^{-3}$).

All the enumerated parameters are interrelated and can be easily estimated when one of them is known. A standard roll of film, 7 cm wide, 1,800 m long and 0.02 mm (+/-155) thick, has a mass of 25.9 kg (Koprysz, 2011). Extension of the former length and relatively small narrowing of the film, which takes place during the wrapping operation, is important only for the conversion of the area of the film to its mass in kilograms. This change can be corrected by means of a contant coefficient which depends merely on the properties of the film of a particular brand. More illustrative and with a lesser number of components will be a theoretical comparison of variants by the specific consumption of the area of the film per unit of the volume of the forage to be sealed (m^2 m^{-3}). For experimental comparison of variants it is more convenient to express the specific consumption in the units of the mass of the film per unit of the volume of forage which is determined by weighing the roles of the film before and after wrapping.

RESULTS AND DISCUSSION

The specific consumption of the film per unit of the mass of forage Z_m (m^2 kg^{-1}) can be expressed as:

$$Z_m = Z_v / \gamma \tag{1}$$

where Z_v – the specific consumption of the film per unit of the volume of forage, m^2 m^{-3}; γ – bulk density of forage, kg m^{-3};

The consumption of the film is in inverse relation to the bulk forage density. Thus, increasing the pressing density by balers is an important reduction factor for the consumption of the film (Skonieczny, 2009; McEniry 2011). However, this process of pressing moist forage (in reality green forage with the 55–60% moisture content is used) has physical limits. Since the subject of this investigation does not concern a study of the factors affecting the baling density of forage, we will proceed from the assumption that this parameter is the same in all the variants discussed. This assumption will allow avoiding a great number of superfluous details (mathematical designations), and a criterion for the comparison may be the consumption of the film (by area) per unit of the volume of forage. As regards the initial dimensions, during the wrapping process the film increases in length but decreases in width; yet the value of these changes is also the same in all the variants, and therefore it is not taken into account when determining the comparative analytical relationships. If necessary, it has to be considered only in order to correct formulae for the comparison of the calculated (by area) and experimental data about the consumption of the film.

The widely practiced methods of individual wrapping of the round bales have an apparent shortcoming that irrational overlapping of the film occurs on the end surfaces (i.e. the film is laid on them) 2–3 (4) times more than on the cylindrical part of the round bale (Fig. 4). In our previous investigations (Ivanovs, 2005) we have made a detailed study of the process of individual wrapping of cylindrical and square bales with the film, as well as of the factors affecting the consumption of film. Therefore we will indicate only the earlier obtained final relationships. We should note merely that the width of the film $\boldsymbol{b}$ and the width of the overlap $\boldsymbol{c}$ determines the efficiency of the machines but not the consumption of film.

The theoretical specific consumption of the film per unit of the volume of forage ($\boldsymbol{Z}_{r1}$, m^2 m^{-3}), when a single round bale of forage is wrapped, is expressed by the following equation (Skonieczny, 2009):

$$Z_{r1} = \frac{4\pi D(D+L)i}{\pi D^2 L} = \frac{4(D+L)i}{DL} = 4i(\frac{1}{L} + \frac{1}{D}) \tag{2}$$

For sealing the round bales by in-line wrapping only two already wrapped bales (the first and the last one) are used in practice, to which the ends of the ribbon film are fixed by means of a sticky tape. The specific consumption of film for wrapping a row of round rolls into one layer can be presented as the sum of the areas of the cylindrical part $\boldsymbol{S_{1r}}$ and the area of the film $\boldsymbol{S_{2r}}$ for individual sealing of two round bales related to the summary volume of forage V_{Σ}.

$$S_{1r} = \pi DLi(n+2) \tag{3}$$

$$S_{2r} = 2\pi D(D+L)i \tag{4}$$

$$V_{\Sigma r} = 0.25\pi D^2 L(n+2) \tag{5}$$

$$Z_{rl} = \frac{S_{1r} + S_{2r}}{V_{\Sigma r}} = \frac{\pi DLi(n+2) + 2\pi D(D+L)i}{\pi D^2 L(n+2)0.25} = \frac{4i(Ln + 4L + 2D)}{DL(n+2)} \tag{6}$$

The specific consumption of the film (m^2 m^{-3}) used to wrap a single square bale of forage can be presented in a simplified form by the following equation (Skonieczny, 2009):

$$Z_{sq1} = \frac{(2L + H + B)(H + B)i}{HBL} \tag{7}$$

The consumption of the film to wrap a row (in-line wrapping) of bales can be expressed as the summary area of the end surfaces multiplied by the number of the layers of the film and as the area of the film for the bales placed at the beginning and the end of the line (for instance, four bales are necessarey- for the variant Fig. 3d). The specific consumption of the film per unit of the volume of forage ($\boldsymbol{Z_{sql}}$, m^2 m^{-3}) used for in-line wrapping of the square bales according to the general scheme, shown in Fig. 2b (the variant found in practice when the bales are arranged with the long side perpendicular to the line of the row and in two layers) will be equal to:

$$Z_{sql} = \frac{S_{sq1} + S_{1sq}}{V_{sql}} \tag{8}$$

$$S_{1sq} = (2L + 2h)B(n+2)i \tag{9}$$

$$S_{2sq} = 4(2L + H + B)(H + B)i \tag{10}$$

$$V_{\Sigma sql} = LhB(n+2) \tag{11}$$

$$Z_{sql} = \frac{S_{sq1} + S_{1sq}}{V_{sql}} = \frac{Bi(n+2)(2L+2h) + 4i(2L + H + B)(H + B)}{hLB(n+2)} \tag{12}$$

In the case discussed (Fig. 3d) $h=2H$, then we have:

$$Z_{sql} = \frac{Bi(n+2)(2L+4H)+4i(2L+2H+B)(H+B)}{2HLB(n+2)} = \\ = [B(2L+4H)+4(2L+2H+B)(H+B)(n+2)^{-1}]i \tag{13}$$

The obtained relationships of the consumption of film used for individual and in-line wrapping of bales comprise distinctive components; therefore it is more convenient to trace the impact of separate factors by the graphs which are calculated and built considering the obtained theoretical relationships.

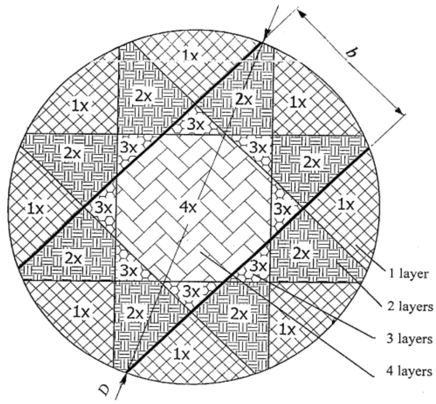


Figure 4. Conditional schemes of possible applying of film on the end surfaces of the round bale: D = 1.2 m, b = 0.5 m.

The impact of the form of the bales upon the consumption of film, when their volumes are shown as an example in Fig. 5. When the volumes of the bales are equal, wrapping of individual round bales needs a lesser amount (by 7.8–8.2%) of film than the wrapping of square bales. When the cross-sectional areas of the bales are equal, in-line wrapping of round bales needs a lesser amount (by 13–17%) of the film than the square bales. When the in-line method of sealing is applied, the consumption of film is almost 2 times less than the individual method (each bale separately).

Comparative values of the consumption of film for in-line wrapping, depending on the cross-sectional area of the bale, are shown in Fig. 6. If the cross-sectional area of the round or square bales arranged in a line is increased, the consumption of film decreases. In practice, the diameters of the round bales generally is not more than 1.83 m, and their cross-sectional areas are correspondingly ~ 2.5 m^2 (Reeveswrapper, 2012). The most widespread balers are round-bale presses with the diameter of 1.2 m (the cross-sectional area 1.13 m^2), and the length of 1.2 m. In contrast to the round bales, the square bales can be stacked one upon the other forming a package of a rectangular cross-section and a great total cross-section. There are wrappers which allow wrapping in the film of square bales stacked in a package 2.4 m wide x 4.6 m high (Reeveswrapper, 2012). The cross-sectional area of such a package of bales is

11 m^2. The length of the line being the same (60 m), the specific consumption of the film for in-line wrapping of such a package of bales is 1.8 times less than a package of bales having dimensions of 0.7 x 1.2 m (0.94 m^2). When the length of the line of bales is increased, the consumption of the film is observed only if the line is short (less than 20 bales), and its further increase is insignificant.

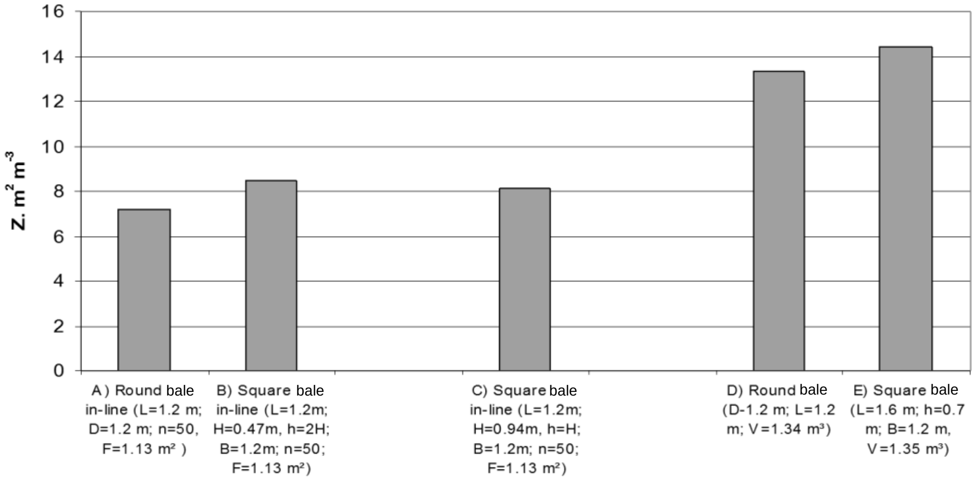


Figure 5. Impact of the form of the bale upon the consumption of the film, with equal volumes of the bales (V = 1.34 m^3) for individual wrapping of the bales and in-line wrapping (cross-sectional areas of the bales are equal F = 1.13 m^2).

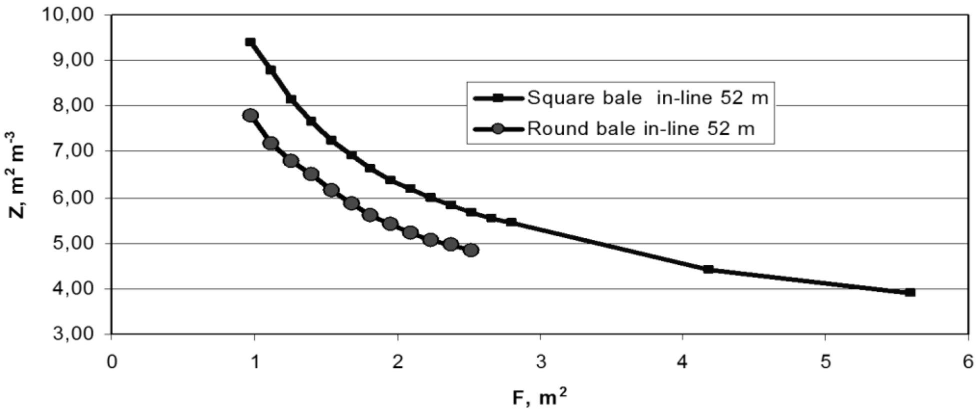


Figure 6. Impact of the cross-sectional area of the line bale F upon the consumption of the film Z (L = 1.2 m; n = 50; for a round bale $S_r = 0.25\pi D^2$; for a line square bale $S_{sq} = hL$).

As it is evident from the obtained theoretical relationships, the consumption of the film for in-line wrapping depends basically on the number of the applied layers of the film, on the dimensions that determine the cross-sectional area of the forage in the line (i.e. the diameter of the cylindrical bale, or the height and width of the package in which a number of square bales are stacked), as well as on the length of the line.

CONCLUSIONS

1) When the volumes of the bales are equal, wrapping of individual round bales needs a lesser amount (by 7.8–8.2%) of the film than wrapping of square bales.

2) When the cross-sectional areas of the bales are equal, in-line wrapping of round bales needs a lesser amount (by 13–17%) of film than the square bales.

3) When the in-line method of sealing is applied, the consumption of the film is almost two times less than the individual method (each bale separately).

4) If the cross-sectional area of the round or square bales arranged in a line is increased, the consumption of the film decreases.

5) An advantage of the square bales wrapped by the in-line method is that a number of such bales (2, 4 or more) can be stacked in a package with a cross-section of a rectangle or a square having greater dimensions, and, consequently, reducing the potential consumption of the film.

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