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Machinery for Harvesting and Processing Cereal Straw for Thatching

Phase 1 Report

Dr Andy Scarlett

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Summary

The production of thatching straw is a complex, time-consuming and very weather-dependent process. Many thatching straw producers use unreliable or outdated machinery and labour-intensive working systems. These potentially threaten the efficiency and long-term viability of straw production.

This report details the findings of Phase 1 of research into the mechanical and operational challenges faced by those harvesting and processing thatching straw. The findings have been informed by detailed discussions with various growers and on-site observations of their equipment and working practices at each stage of the production process. The aim was to define the various advantages and disadvantages. Research concerning agricultural machinery design, operation and relevant patents was also undertaken.

This report documents the two generic approaches currently used in the production of thatching straw, termed Conventional and Alternative. It records methods that some producers have adopted to overcome practical difficulties. The potential for further improvements at all stages of the harvesting process and for all scales of operation is considered, including the mechanisation of processes that currently rely on manual labour. These range from the selection, operation, maintenance and adaptation of machinery, to the purchase or design and manufacture of new equipment. The areas of production most likely to benefit from these improvements are highlighted, and potential next steps are proposed.

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Images

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Front cover image: Conventional harvesting of wheat for thatching straw by binder.
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Executive summary

This research aims to identify appropriate mechanisation solutions and equipment to make the harvesting of thatching straw more efficient, safer, less labour-intensive and more financially viable. Research reported here (Phase 1) focuses on identifying machinery-related issues experienced by thatching straw growers and possible mechanisation improvements. Phase 2 will investigate the practicability of these mechanisation solutions and explore options for implementation.

Harvesting and processing thatching straw is a complex, multi-stage and weather-dependent process. The crop may be processed either as long straw (LS) or combed wheat reed (CWR). In addition, two different generic harvesting approaches have been identified. In that termed the ‘Conventional’ method, the crop is cut (with grain attached) when partly ripe; it is ripened in-field, and then is transported, stored and eventually processed using static equipment, to remove the grain. In that termed the ‘Alternative’ method, the crop is harvested at a more advanced stage of ripeness. The grain is removed from the standing crop, and the straw is then cut, processed and packaged, all as in-field operations. A variety of equipment and techniques are used within each defined approach.

The Conventional harvesting and processing method, as used to harvest approximately 80 per cent of the UK crop, offers the greatest scope for mechanisation-related efficiency improvements and cost reduction. While the Alternative harvesting method is considerably more efficient, some scope for product quality refinements also exists.

Processes that offer the greatest potential for improvement are primarily those that are labour-intensive or involve a poor working environment. They include:

- In-field crop handling – in relation to crop ripening / stooking (Conventional).
- In-field crop packaging – prior to transport to store (Conventional).
- Crop processing: crop material transfer to/from static equipment and overall labour requirement (Conventional).
- Crop processing – improving operator working environment (Conventional).
- In-field crop handling and packaging – to enhance product quality (Alternative).

Growers currently have few options regarding the provision of harvesting and processing machinery. They can use old (often vintage) agricultural machinery, adapt newer agricultural machinery, or design, develop and construct their own bespoke equipment. Due to the small market size and limited scope for significant grower investment, the development of new harvesting equipment is unlikely to be regarded as a commercially viable activity by most machinery manufacturers.

For many growers, the production of thatching straw is a small-scale operation. It is, therefore, unrealistic to expect them to invest very much in developing bespoke mechanisation solutions to these highlighted problems. Alternatively, the development of such solutions might be undertaken cost-effectively and relatively quickly by a third party (or parties), such as Historic England or Historic Environment Scotland, working in conjunction with growers.

However, to improve the economic viability and sustainability of their operations, growers need to invest (time and/or money) in appropriate mechanisation solutions, and also to take a more active role in selecting, developing and refining such solutions. Such involvement is likely to encourage a greater level of eventual take-up within the industry.

Potentially the most effective route by which improvements in crop harvesting and processing could be transferred to the end-user (following machine development and proof-of-concept demonstration, ideally in conjunction with a grower consortium or an industry association), would be by providing free-to-use design drawings. These would enable growers or their agents to construct or adapt appropriate machinery for their own use. Other independent bodies have used this approach in the past within this sector, with some success.

In addition to investigating the practicability of the above-mentioned mechanisation solutions and exploring options for implementing the most promising examples (as intended within Phase 2), the following activities are recommended as complementary next steps:

- Host a ‘grower workshop’ event to engage with the industry, disseminate research findings to date and obtain feedback to help guide future activities.
- Develop and actively disseminate best practice technical guidance for growers, regarding selection, use and possible adaptation of harvesting and processing equipment. Specific objectives are to optimise/improve product quality, reduce labour and production costs, obtain best performance (via appropriate set-up and pre-season maintenance) and improve operator working environment and safety.
- Explore possible avenues by which to collaborate with growers in the future development and possible proof-of-concept implementation of more refined and efficient harvesting machinery. This could include the establishment and coordination of consortia to bid for government research and development funding in the agricultural sector.
- Encourage the establishment of channels and/or opportunities for the exchange of mechanisation ‘hints and tips’ between growers. However, the subject matter need not necessarily be limited to machinery-related topics.

1. Introduction

1.1 Background

The production of cereal straw for thatching is a small but vitally important industry in the UK. The continued availability of good quality thatching straw is essential for the maintenance of many listed and historic buildings.

Historic England and Historic Environment Scotland share a common goal to secure the sustainable production of materials for traditional thatching in the UK. They recognise that growers of cereal straw for thatching face many challenges. The widespread reliance on old, inefficient and unreliable machinery for straw harvesting and processing is a significant issue.

Historic England and Historic Environment Scotland, therefore, believe that addressing this issue would contribute significantly to making the UK thatching straw industry more resilient. It would support the needs of existing growers, and potentially make the sector more attractive to new entrants.

1.2 Aims and objectives

The primary aim of this investigation is to identify appropriate mechanisation solutions, and associated equipment, which will make the production of thatching straw a more efficient, safer and less labour-intensive process – and also make it a less risky and more financially viable enterprise.

The work is structured in two phases. Phase 1 (reported here) focused on gathering information and identifying machinery-related issues as currently experienced by thatching straw growers. Possible options for mechanisation improvements were also considered.

It is envisaged that Phase 2 will explore the feasibility of some of the potential mechanisation solutions and review options for their provision.

Central to the work of Phase 1 was the desire to appreciate what constitutes good quality thatching straw, to understand its properties and to appreciate the ways in which product quality may be influenced by a range of factors. These include different types of harvesting and processing equipment and the ways in which it is used.

1.3 Report structure

This report is structured as follows:

- **Section 2** reviews the different types of cereal straw used for thatching in the UK, and the way(s) in which it is influenced by crop harvesting and processing techniques.
- **Section 3** reviews the two generic methods used for the harvesting and processing of thatching straw in the UK. The individual stages of each process are explored, together with the machinery and operating techniques employed. The perceived advantages and disadvantages of each element of each process are reviewed.
- **Section 4** considers the scope for improving the operational efficiency of thatching straw harvesting and processing machinery, and the possible limitations that may exist.
- **Section 5** outlines mechanisation options that could potentially improve the efficiency of thatching straw harvesting and processing operations.
- **Section 6** provides recommendations for next steps and possible future activities. It also considers potential pitfalls and opportunities.
- **Section 7** presents a summary of the findings and the conclusions of Phase 1 of the investigation.

2. Cereal straw for thatching

2.1 Types of thatching straw

Recent estimates suggest approximately 3,500 acres (1,400ha) of cereal straw are currently grown in England (very little is grown in Scotland and Wales). Approximately 60 per cent of this area comprises winter wheat; the remaining 40 per cent is triticale, a cross between wheat and rye. As shown in Figure 1, the growing of cereal straw for thatching is very heavily concentrated in the South West, with the East of England and the South East accounting for the majority of the remainder.

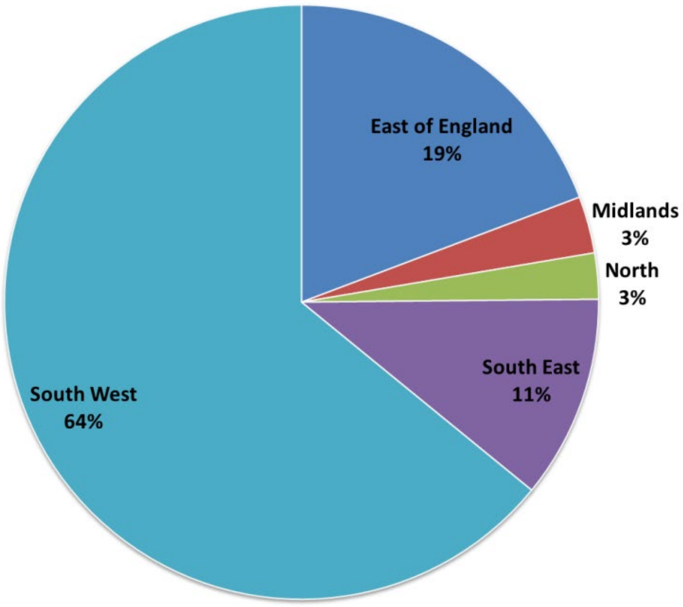

Figure 1: Regional distribution of straw grown for thatching in England. [Source: Stradling]

Largely irrespective of whether the straw is derived from wheat or triticale, there are two very distinct types of thatching straw produced in the UK: long straw (LS) and combed wheat reed (CWR), also known as 'Devon reed'. These quite different materials result from the use of different mechanical crop treatment techniques during harvesting or, more usually, during post-harvest processing (*see* Section 2.2). LS and CWR are also subject to different treatment by the thatcher during preparation and installation. However, in all instances, it is desirable for the straw to be long, ideally in the range of 3 to 4ft (0.9–1.2m).

Historically, there was a distinct regional distribution of the two types of thatching straw. CWR was used throughout the West Country, whereas LS was dominant in the South, the East and in Central England. However, over a period of time CWR has encroached eastwards to a significant degree, to the extent where LS is now confined primarily to the East of England.

2.2 Influence of crop harvesting and processing techniques

Thatching straw can be harvested and processed in a number of ways, but it is always a multi-stage process involving a number of sequential steps. While in all instances the grain is removed from the straw, in the majority of cases this activity is not performed 'in-field', but rather as a separate post-harvest processing operation, frequently conducted over the winter months. It is the precise nature of the processing operation and the equipment used that determines whether the end product is CWR or LS.

For CWR, the plant stems are mechanically 'combed' to remove the grain, plus all leaf material and broken straw, leaving the stems straight and undamaged. For LS, the crop is usually harvested in an identical way, but the grain is removed by a threshing process. This bruises the plant stems to a degree, but leaves a significant proportion of leaf material attached. Pieces of shorter straw may also be present in the final mix of material.

Furthermore, irrespective of the end product (that is, LS or CWR), there are two generic approaches to thatching straw harvesting and processing: the 'Conventional' method and the 'Alternative' method:

- **Conventional:** Crop is cut while part ripe, and then ripened in-field. Grain is removed as a separate, post-harvest operation, usually over winter.
- **Alternative:** Grain is removed in-field when the crop is at a more advanced stage of ripeness. Straw is subsequently harvested and processed as a separate in-field operation.

Opinion differs among some thatchers regarding the characteristics and acceptability of straw produced by the Alternative method. At the time of writing, the Alternative method has been in use for more than 30 years, and it is estimated that it accounts for approximately 20 per cent of the thatching straw produced in the UK.

This means that a significant majority (80 per cent) of thatching straw is still harvested and processed using the Conventional method. The generic approaches for thatching straw harvesting and processing are, therefore, as summarised in Table 1.

Irrespective of the method used, the harvesting and processing of thatching straw involve several essential steps, including crop cutting, ripening or conditioning, processing/grain removal and crop packaging, both for interim handling (transport from field to store) and for onward sale. The order in which these activities are performed, their precise nature and the machinery used vary depending on the product and the harvesting/processing method (*see* Table 1 and Section 3).

Table 1: Generic approaches for thatching straw harvesting and processing.

Long straw **Conventional method**	**Long straw** **Alternative method**
Combed wheat reed **Conventional method**	**Combed wheat reed** **Alternative method**

The key elements of these generic harvesting/processing approaches, and the likely characteristics of the end products, are summarised below:

Long straw: Conventional method

- Cut when grain and straw are partially ripe, and ripened in-field in 'stooks' (groups of sheaves stood upright).
- Subsequently threshed as a separate, remote operation.
- Majority of leaf material retained on the plant stem (including flag leaf).
- Stems bruised during the threshing and/or handling and packaging processes.
- Requires considerable preparation (yealming) before placing on the roof.

Long straw: Alternative method

- Grain removed in-field by a 'stripper header' attachment on a combine harvester when the crop is at a more advanced stage of ripeness, but not necessarily fully ripe.
- Straw cut as a separate operation. Heads/ears may be subject to additional combing to remove any residual grain.
- Cut straw bound into sheaves or handled loose, before being further packaged for transportation, storage and eventual onward sale.
- Flag leaf removed, and possibly also the heads/ears, during stripping or subsequent combing.
- All crop harvesting, processing and packaging operations performed in-field.
- Plant stems are not bruised, unless as a result of the packaging process.
- Product requires considerably less preparation before placing on the roof.

Combed wheat reed: Conventional method

- Cut when grain and straw are partially ripe, and ripened in-field in stooks.
- Subsequently combed as a separate, out-of-season operation.
- All leaf material removed from the plant stem. Heads/ears are usually left intact.
- Plant stems are straight and are not bruised during combing or the handling/packaging processes.

Combed wheat reed: Alternative method

- Grain removed in-field by a stripper header when the crop is at a more advanced stage of ripeness, but not necessarily fully ripe.
- Straw cut as a separate operation. Combed in-field 'on-the-move', and bound into 'trusses'.
- Trusses subsequently packaged into larger bundles or bales for transportation, storage and onward sale.
- All crop harvesting, processing and packaging operations performed in-field.
- Heads/ears are left intact in some seasons, but largely removed if harvesting conditions are dry and/or the crop is very ripe.
- Majority of the plant stems are straight and not bruised during the combing, handling or packaging processes. Some standing stems may be damaged by passage of the combine wheels during the grain removal (stripping) process.

3. Harvesting and processing methods

Long straw (LS) and combed wheat reed (CWR) may be harvested and processed either by Conventional or Alternative methods. This section explores the individual processes and specific machinery used in each stage of these generic methods. Their respective operational advantages and disadvantages, as identified during detailed discussions with thatching straw growers, are also reviewed.

3.1 Conventional method

3.1.1 Overview

In the Conventional harvesting and processing method, the cereal crop is cut while partly ripe and subsequently ripened in-field. The straw is then transported to store, possibly having first been formed into intermediate packages to facilitate mechanical handling. The grain is removed from the straw by a separate processing operation, usually performed over winter, and the straw is repackaged for storage prior to onward sale. The various operations and equipment involved are summarised in Figure 2.

In many respects (certainly in the case of LS), the generic crop harvesting and processing techniques and equipment employed are similar, if not identical, to those used for the commercial harvesting of cereals in the UK prior to the introduction of the combine harvester.

The practical advantages of the Conventional method include a reduced risk of (potentially total) crop loss caused by 'lodging' (weather-induced flattening) prior to harvest. Also while ripening in-field in stooks, the crop has a degree of weather resilience. However, by the nature of the process, it is exposed to the vagaries of the weather for an extended period. If weather conditions are poor during harvest, the requirement to ripen the crop in-field in stooks may well be a disadvantage.

Disadvantages of the Conventional method include its dependence on old and potentially unreliable equipment. A greater issue is the very high level of manual handling and re-handling of the crop material, from initial cutting through to processing and eventual re-packaging for storage and onward sale. In this respect, the Conventional method is extremely labour-intensive.

Opportunities for improvements in process efficiency and overall mechanisation are discussed further in Sections 4 and 5.1.

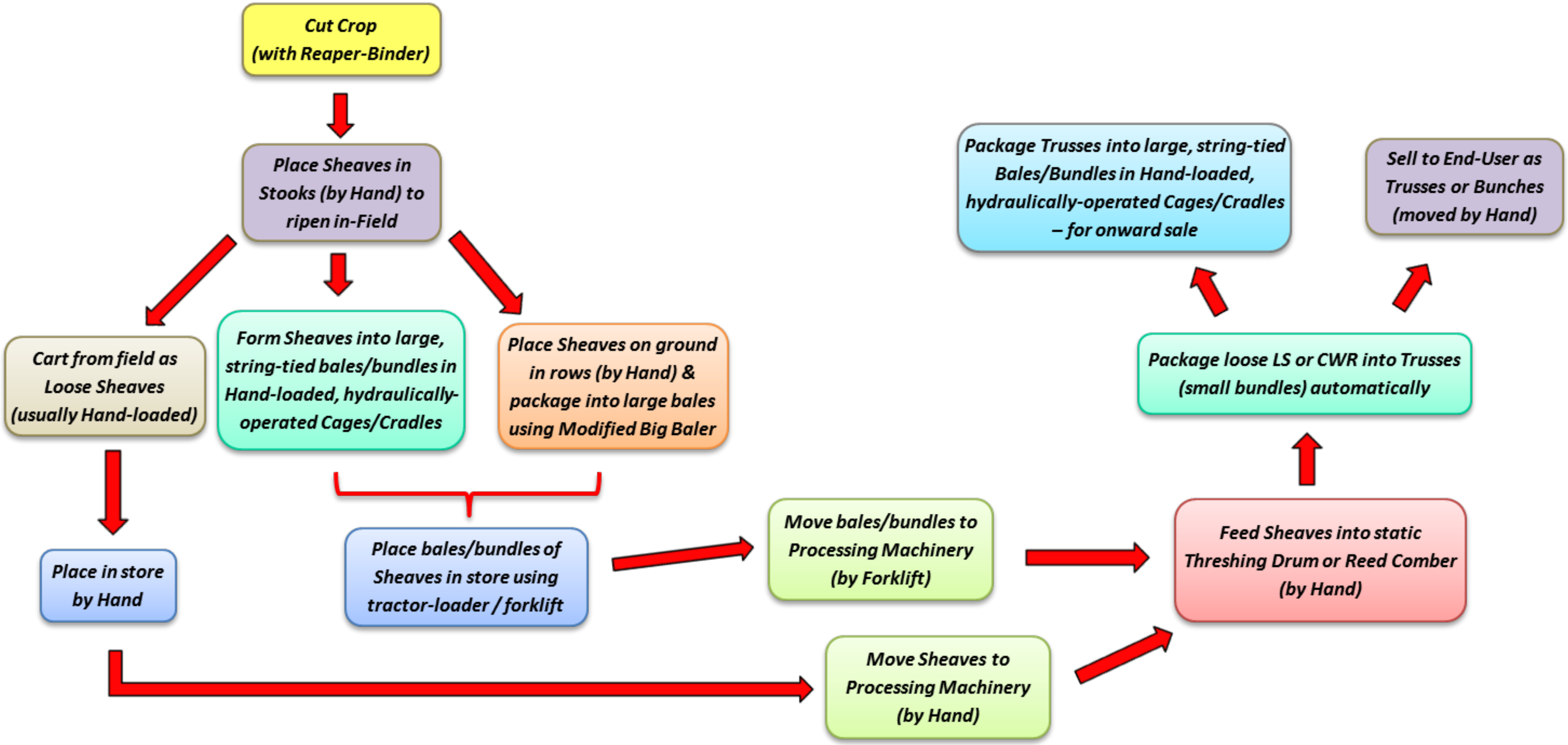

Figure 2: Typical activities performed when harvesting and processing thatching straw by the Conventional method.

3.1.2 Crop cutting

Figure 3: Conventional power take-off (PTO) powered binder at work.

Thatching straw harvested by the Conventional method is cut using a binder, also known as a reaper-binder or self-binding reaper (Figure 3). Originally developed in the late 1870s and pulled by a team of horses, the binder and its associated harvesting techniques remained the dominant method of cereal harvesting in the UK well into the 1950s, when it was progressively replaced by the combine(d) harvester. Nonetheless, the 1958 agricultural machinery census of England and Wales recorded that more than 99,000 binders were still present on farms, compared with 40,000 combine harvesters.

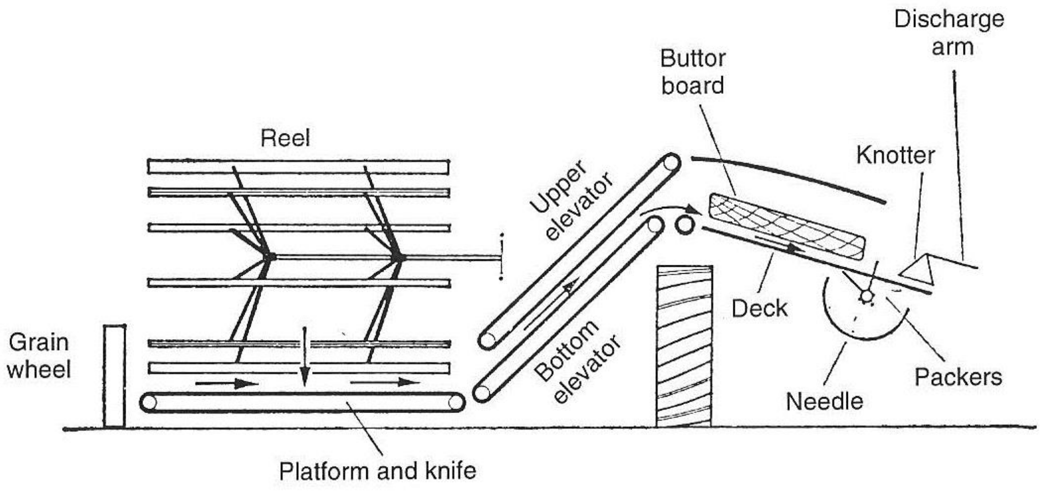

Figure 4: Conventional binder: schematic view. [Source: Bell 1993]

A conventional trailed binder (Figure 4) cuts the standing crop using a series of knives, which reciprocate between a row of fingers. The cut crop is then transported sideways to the 'knotter deck' by a series of elevator conveyors or 'canvasses'. Here, it is packaged and bound into sheaves by a series of packer fingers or 'gabblers' and an automatic knotter mechanism. Each sheaf, bound by a single band of (usually sisal) twine, is then discharged onto the ground by a rotating discharge arm.

A binder can be fitted with an optional 'sheaf carrier': a steel basket installed below the knotter deck that collects groups of six to eight sheaves before dropping them to the ground. By forming successive groups of sheaves in transverse rows across the field, this device was intended to make the subsequent 'stooking' operation quicker and more labour efficient. Unfortunately, sheaf carriers did not achieve widespread popularity in the UK.

The mechanisms of horse-drawn binders were driven by a series of shafts, gears, chains and sprockets from the main 'land' wheel that supported the machine. Some later designs, intended for use with tractors, were also land wheel-driven, but many tractor-drawn binders derived power directly from the tractor's power take-off (PTO) shaft (*see* Figure 3). This arrangement makes the binder's operation independent of forward motion, which can be particularly beneficial in difficult harvesting conditions. Despite this, some larger thatching straw growers still favour land wheel-driven binders, apparently for their superior work rates in favourable operating conditions.

Binders were produced with cutting widths of 5, 6, 7 and even 8ft (1.5, 1.8, 2.1 and 2.4m). However, given the higher plant density of most modern thatching straw crops, there appears to be a preference for 6ft (1.8m) cut machines. Attempts to use wider machines have often resulted in overloading of the gabbling and knotting mechanisms and the production of excessively large sheaves. In good conditions, work rates of 8 to 10 acres/day (3.2–4ha/day) are reported by most users.

When pulled by a team of horses, a binder was operated by one person. They were responsible for controlling both the horses and the machine via a series of levers. However, when tractor power replaced horsepower, an additional tractor driver was required. Some later designs of binder allowed the tractor driver to also control the machine, thereby saving labour. In favourable harvesting conditions, some growers now dispense with a separate operator on conventional trailed (as opposed to tractor-mounted) binders and simply rely on an observant tractor driver.

Some growers use modern designs of PTO-driven binders, mounted on the tractor's rear three-point (3pt) linkage, but these have yet to find widespread favour. Such machines, which are manufactured to a similar design in India, Turkey and other countries, are discussed further in Section 5.1.

To summarise, the advantages and disadvantages of conventional binder operation are as follows:

Advantages

- Tried and tested machine.
- Well-proven harvesting technique.
- Low cost: old second-hand machines are still available, albeit in reducing numbers.

Disadvantages

- Requires two operators (usually, but not always).
- Awkward and time-consuming to convert between road transport and field-working modes.
- Requires high level of maintenance.
- Poor machine reliability (due to machine age and accrued working hours).
- Very poor/non-existent availability of replacement parts.
- Questionable safety of (binder) operator's environment.

3.1.3 In-field crop ripening (stooking)

In-field ripening is an essential element of harvesting thatching straw using the Conventional method. The crop is cut and bound into sheaves by the binder when both the straw and grain are partly ripe: typically 10 to 14 days before it would be considered sufficiently ripe to harvest by combine. At this stage, the grain is still 'cheesy' in texture, generally around 30 per cent moisture content, and the straw is yellow with some traces of green remaining.

Unless both the ground and the forecast weather conditions are extremely dry, it is necessary to arrange the sheaves in stooks to fully ripen and dry. This laborious and entirely manual process (known as stooking, stitching or shocking) involves collecting individual sheaves and arranging them with the ears uppermost, in stooks of eight or 10 sheaves (Figure 5).

Depending on the subsequent weather conditions, the sheaves remain in stooks for 10 to 20 days, until they are completely dry and fit to package and/or transport, either to store or for in-field threshing. While in stooks, the (largely upright) sheaves have a degree of resistance to inclement weather, but any poorly made stooks that fall over will require remaking. If subject to prolonged wet weather, stooks may need to be remade in order to dry out: the sheaves are turned in the (remade) stook to expose their wet inner faces and facilitate drying. Stooking and any re-stooking, therefore, constitute a very significant manual labour requirement.

Figure 5: Sheaves of wheat ripening in stooks.

The advantages and disadvantages of in-field ripening (in stooks) are as follows:

Advantages

- Permits crop to be cut when partly ripe and thereby develop greater mechanical resilience.
- Provides a degree of weather resilience while ripening.

Disadvantages

- Very high manual labour requirement (and associated cost).
- Limited work rate (dependent on the available labour force).
- Usually dictates subsequent manual handling of the crop.
- In a wet harvest period, the crop can suffer extended exposure to poor weather conditions and can potentially deteriorate.

3.1.4 Crop packaging and transportation

Once the straw and grain have ripened and the straw is completely dry, it is transported either to the store to await processing or directly to appropriate processing equipment if threshing in-field. Some growers transport the unprocessed crop on agricultural trailers as loose sheaves. These, therefore, require both manual loading in-field and subsequent unloading at the store. However, a majority of growers employ equipment to form the sheaves into large intermediate packages in-field. These are then loaded and transported by mechanical means, such as telehandlers and trailers (Figure 6).

Figure 6: Telehandler loading packages of thatching straw onto an agricultural trailer.

Within any crop packaging process, there is a risk of physical damage: in this instance, damage to the straw and loss of grain from the ears. Maintaining straw quality is the primary concern, particularly in the case of CWR. With LS, a degree of stem bruising is acceptable or even desirable.

This investigation found three generic types of equipment are commonly used to form unthreshed/uncombed sheaves of thatching straw into intermediate packages:

- Manually loaded, hydraulically operated packaging cage (cradle).
- Modified Howard Bigbaler (vintage large square baler).
- Standard fixed-chamber large round baler.

Their use, advantages and disadvantages are discussed below.

A. Manually loaded, hydraulically operated packaging cages (cradles)

Figure 7: Manually loaded, hydraulically operated packaging cages (cradles).

These are typically small tractor-drawn trailers that carry a substantially engineered cylindrical steel cage framework, the hinged upper section of which may be opened or closed hydraulically (Figure 7).

In use, up to five strands of heavy-duty polypropylene baler twine are drawn from front-mounted spools and placed around the lower half of the cage. The cage is then loaded manually, with up to 90 sheaves, and closed to compress the load, thereby forming a cylindrical package. This action also passes the strings around the upper periphery of the package, enabling them to be tied, manually, at the rear. The cage is then opened and tilted hydraulically to discharge the package for subsequent collection.

With the addition of sheet steel side panels, the same equipment can be used to package trusses of threshed or combed straw for onward sale (*see* Section 3.1.6).

A range of cage sizes and designs are used, some capable of accommodating up to 160 sheaves. Some larger growers have developed mechanised cage-loading systems to improve in-field work rates.

Advantages

- Simple, robust equipment. Easy to design, build and operate.
- Minimal damage to the straw.
- Less risky than baling in unpredictable weather conditions. Crop stays in the stook until formed into packs. When awaiting packaging, sheaves are not lying in exposed swaths on the ground.

Disadvantages

- High manual labour requirement (about two to four people per cage).
- Limited daily work rate per machine (for manually loaded machines). Poor productivity per person.
- Not cheap (about £4,000 per machine).

B. Howard Bigbaler (large square baler)

Figure 8: Howard Bigbaler baling straw after combining. NB: Not shown baling thatching straw.

The Howard Bigbaler (Figure 8) is a low-density, 'press'-type, large square baler, designed and built in the UK during the 1970s. It achieved considerable commercial success both at home and abroad. However, the bales produced by the Bigbaler were originally intended for the barn-drying of hay and so were not as dense or of such a defined rectangular shape as those produced by subsequent North American large square balers. The Howard Rotavator Company stopped producing the Bigbaler in the early 1980s, and the company ceased trading in the 1990s.

The relatively gentle crop handling and low-density baling characteristics of the Bigbaler, which originally earnt it criticism, are highly desirable when packaging unthreshed thatching straw in-field, where minimising straw damage is important. Consequently, second-hand Bigbalers are now highly sought-after by thatching straw growers.

A key feature of the Bigbaler that makes it so well suited to packaging thatching straw is its wide (5ft/1.5m) crop intake 'throat' and bale chamber. Crop is fed from a tined pick-up reel (Figure 9, A), and then is transferred through the throat into the bale chamber by a bank of nine packing fingers (B). As the throat is the same width as the bale chamber, the crop is not compressed laterally, and damage is minimised. As the crop enters the bale chamber, the front wall reciprocates to and fro, acting as a packing plate and pushing the material rearwards, thereby forming the bale. When sufficient material has been collected, the baler's knotter mechanism is tripped to tie three strands of polypropylene twine, which have been paid out around the bale during its formation. The rear gate is then unlatched, and the completed bale is pushed out of the chamber by the formation of the next one.

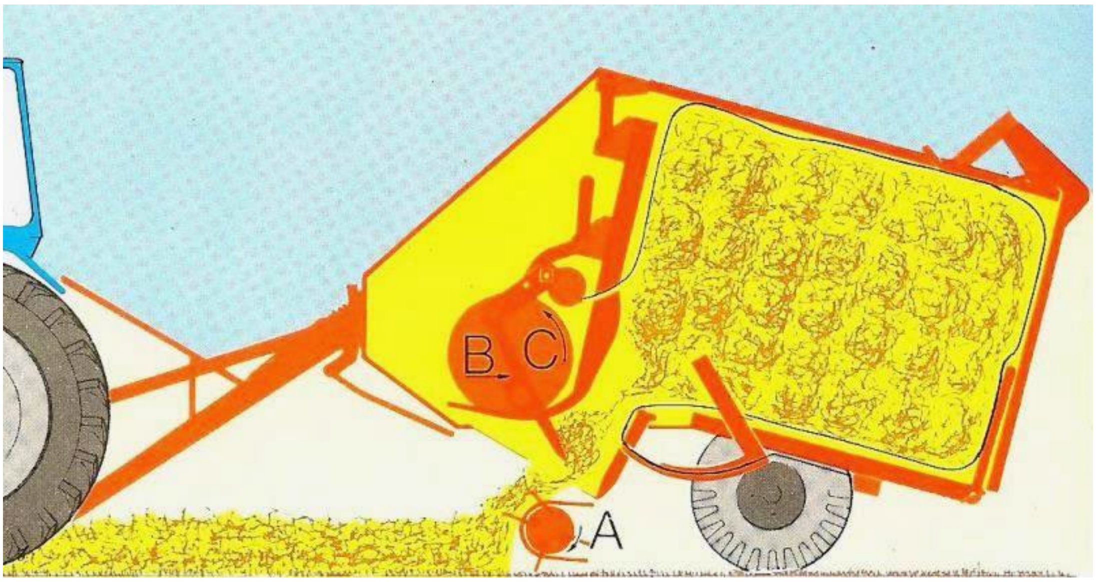

Figure 9: Howard Bigbaler: cross-sectional view.

Use of a Howard Bigbaler for packaging unthreshed/uncombed thatching straw requires a bespoke operating technique. The bound sheaves are taken from the stooks manually, and laid transversely in swaths (longitudinal rows), with their heads and butts (stem ends) alternating. The tractor then straddles the row, and the sheaves are collected by the baler, again in transverse (cross-wise) orientation.

Growers have found that the Bigbaler benefits from certain bespoke modifications to improve the efficiency of crop pick-up, and also to minimise crop damage during baling. However, these old machines appear to be very effective in this role. Although manual labour (up to five people) is required to rearrange the crop from stooks into suitable swaths, thereafter a single baler – supported by two further operators with telehandlers and trailers – can clear 20 acres (8ha) of crop per day from field to store.

Advantages

- High daily work rate.
- Little damage to straw (if machine is suitably modified).
- Given its complexity, a reasonably priced machine.

Disadvantages

- Some manual labour required (to form swaths for the baler).
- Crop (temporarily) at greater risk of weather damage when lying in swath.
- Baler requires careful operation and attention to detail.
- Requires good pre-season servicing and maintenance (an old machine).
- Requires certain modifications to operate effectively.
- Limited availability of certain replacement parts.
- Machine no longer in production. It is becoming harder to source second-hand, so market prices may increase.

C. Fixed-chamber large round baler

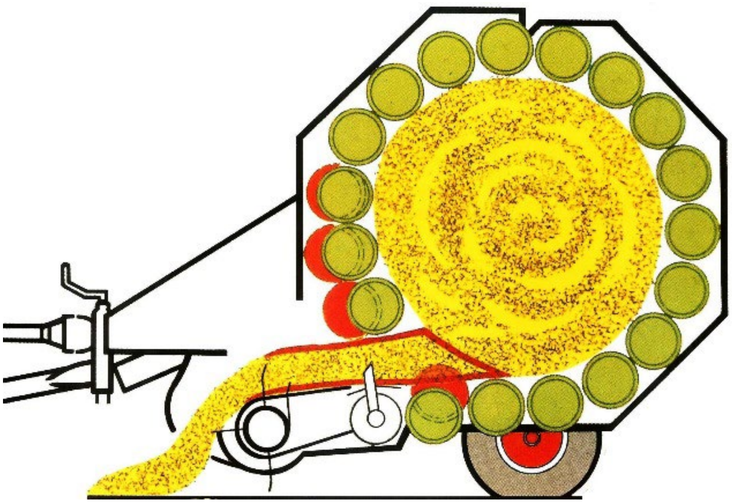

Figure 10: Fixed-chamber large round baler: cross-sectional view. (Claas)

Large round balers are highly popular and readily available agricultural machines. They are used for baling hay, straw and (frequently) grass silage. Unlike square balers, round balers pick up the crop and roll it into a cylinder within the machine to create a bale. The bale is then packaged, usually by wrapping the circumference in polypropylene ‘netwrap’, prior to it being discharged from the bale chamber. During the wrapping and discharging phases, the baling process has to be momentarily paused.

There are two generic types of large round baler: variable chamber and fixed chamber. These terms refer to the position and geometry of the bale-forming elements (typically steel rollers and/or rubber belts) within the bale chamber. Variable-chamber balers typically use rubber-coated belts to roll the crop and form the bale. The belts maintain contact with the bale at all times, compressing incoming crop layers to form a package that is consistently dense from the outer circumference to the core (*see* Figure 35).

Fixed-chamber balers typically employ power-driven steel rollers arranged in a fixed position/geometry. Crop entering the bale chamber is initially rotated only by the lower rollers. As the bale grows, it progressively contacts the mid and higher placed rollers. Only as the bale nears completion does it come into contact with all the rollers around the circumference of the bale chamber. This process creates a bale with a soft core and a dense outer shell, which is particularly beneficial in certain applications, such as hay and silage baling.

Some (primarily LS) growers successfully use fixed-chamber round balers to package unthreshed sheaves into soft bales for transport from field to store. The preliminary process is identical to that used for a Howard Bigbaler: forming the sheaves into swaths, and laying each sheaf transversely, head to tail with its neighbour.

Baling must be performed with care, to avoid undue straw damage or grain loss. Unfortunately, the bale chambers of most round balers are only 4ft (1.2m) wide, which leaves little room to spare when attempting to bale 3 to 4ft (1–1.2m) tall sheaves. As previously mentioned, in the case of LS, a degree of crop stem bruising is acceptable, if not desirable. However, it is debatable whether round baling would be an acceptable packaging technique for straw destined for CWR.

Advantages

- High daily work rate (at least 20 acres/8ha per day).
- Readily available equipment.
- Good spare parts availability.
- Given its complexity, a reasonably priced machine.

Disadvantages

- Some manual labour required (to form swaths for the baler).
- Crop (temporarily) at greater risk of weather damage when lying in swaths.
- In this application, baler requires careful operating technique.
- Greater risk of straw damage. Potentially acceptable for LS, but probably not for CWR.

3.1.5 Crop processing

When harvesting and processing thatching straw using the Conventional method, the grain is removed from the straw during a separate post-harvest processing operation. In some circumstances, this is done at harvest time at the field edge, but – both historically and currently – it is more commonly undertaken over the winter months. Some claim this over-winter scheduling is because the grain is easier to remove after the crop has been stored for several months. However, historically, the timing of threshing or combing more likely coincided with the greater availability of on-farm labour to perform this demanding task, and also the availability of contractor-owned threshing equipment. Irrespective of the reasoning, it is necessary to balance the length of time an unthreshed crop remains in store against the increased risk of rodent damage.

As discussed in Section 2.2, it is the precise nature of the processing operation and the equipment used that determines whether the eventual end product is LS or CWR.

A. Threshing machine (threshing drum) (long straw)

In the case of LS, the grain is removed from the straw by a threshing process, performed by a threshing machine, more commonly known as a ‘threshing drum’. Mechanical threshing machines were first invented in the late 18th century, and by the late 19th century the design of the modern threshing drum (Figures 11 and 12) had evolved: thereafter, it remained largely unchanged until production ceased in the mid-1950s. Unquestionably a complex piece of machinery, the modern threshing drum (Figure 13) performs many more operations than its name suggests. In sequence these include:

- Threshing the grain (or seeds) from the plant stems.
- Separating loose grain from the threshed straw.
- Removing short straw (cavings) and chaff from the grain.
- Cleaning (dressing) the grain to remove impurities (for example, weed seeds).

These activities focus on the separation and recovery of the grain from the other plant material, and then final cleaning or dressing the grain. In the latter respect, a correctly adjusted threshing drum is in fact considerably more capable than a modern combine harvester. The straw, while of primary interest for thatching, is still treated as a by-product by the threshing machine.

Figure 11: Ransomes AM 54 threshing drum, operational in January 2023.

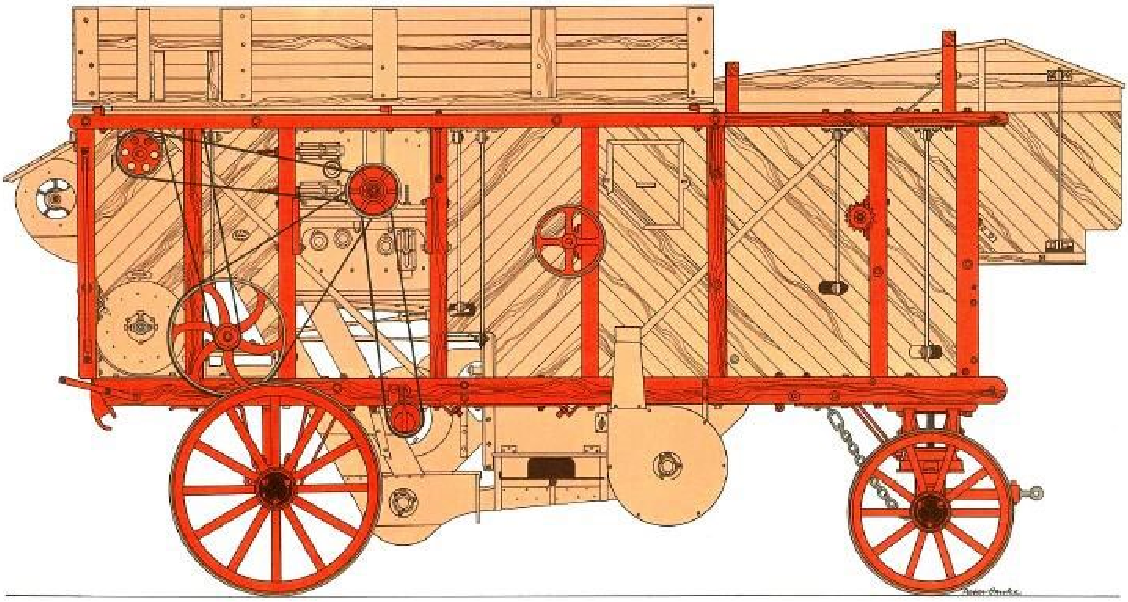

Figure 12: Ransomes A 54 threshing drum, *c.* 1935.

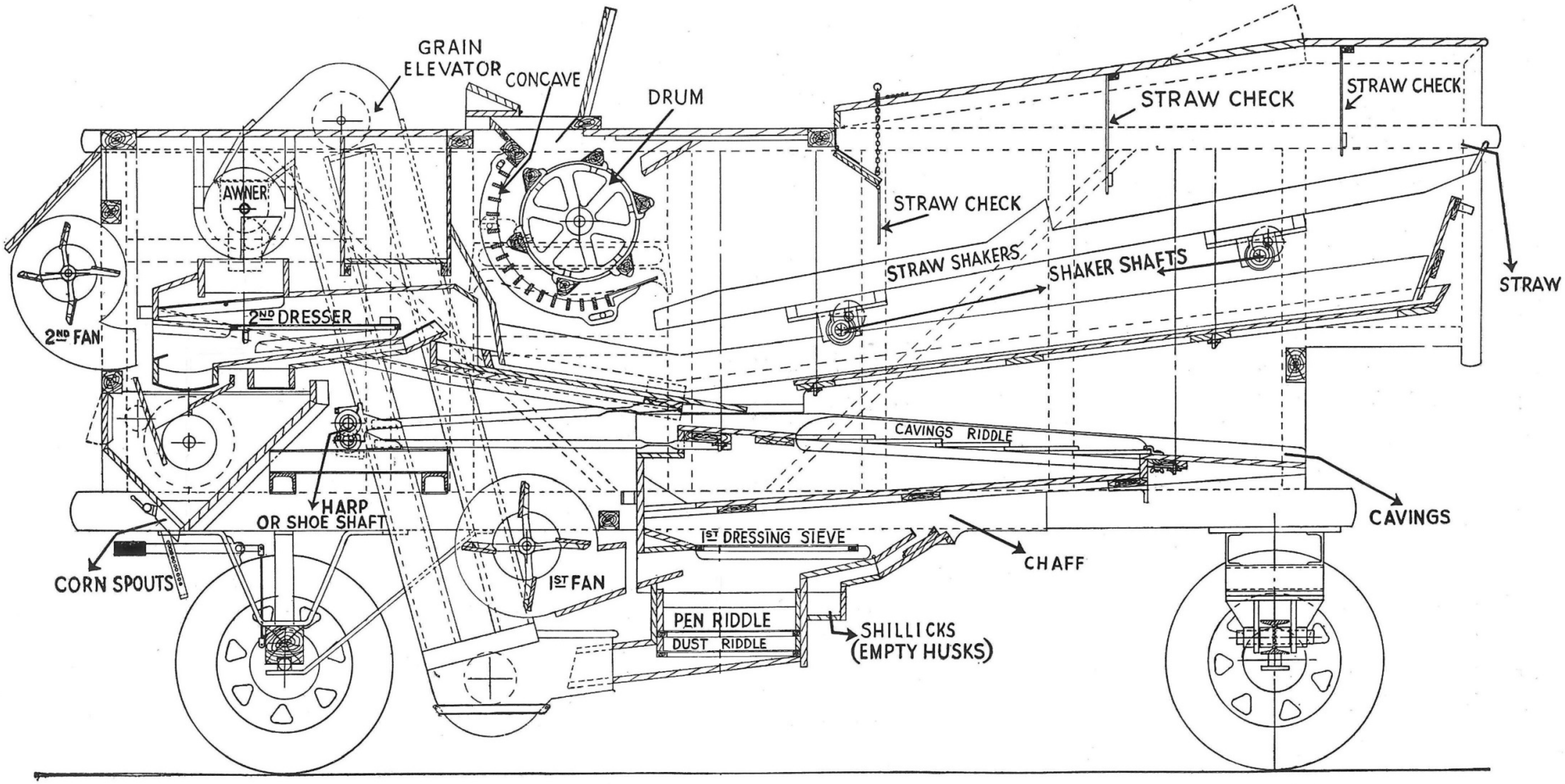

Figure 13: Typical ‘modern’ threshing drum: cross-sectional view. (Barclay, Ross & Hutchison Ltd)

When processing LS, the entire crop is passed through the threshing drum, to remove the grain and chaff from the plant stems (Figure 13). This is effected by a threshing cylinder or drum, which rotates at high speed within a curved steel grating (the concave). Horizontal steel beater or ‘rasp’ bars are arranged around the periphery of the cylinder and the concave is positioned to give a precise (adjustable) gap between its inner surface and the rasp bars.

The crop is manually fed into the top of the threshing drum, and is drawn into the gap between the rotating threshing cylinder and the stationary concave. The rasp bars then rub the ears of wheat against the concave, and remove the grain and chaff from the plant. Loose grain remaining in the threshed straw is then shaken out by the oscillating action of the straw walkers or ‘shakers’. These also convey the straw out of the machine for subsequent packaging or stacking. The grain is then separated from the chaff and other impurities by a series of air-assisted sieves and cleaning mechanisms.

During the processing of LS, passage through the drum and concave causes a degree of mechanical damage to the straw. The plant stems are bruised slightly, but a significant proportion of leaf material remains attached. Pieces of shorter straw may also be present in the final mix of material, but the chaff and cavings are removed.

Steps are usually taken to minimise mechanical damage. It is normal practice to cut the strings (bands or bonds) from the sheaves and feed the crop transversely into the threshing drum (across the width of the machine), so the plant stems are presented parallel to the revolving rasp bars. Machine output is proportional to drum width, so threshing machines were built in a variety of widths (for example, 27, 36, 42, 48, 54 and 60in./0.7, 0.9, 1.1, 1.2, 1.4 and 1.5m). However, when threshing thatching straw, it is important to use a machine of sufficient width to accommodate the likely 36 to 48in. (0.9–1.2m) long plants, with some room to spare. Fortunately, the majority of threshing machines built were 54in. (1.4m) wide, so most surviving examples are of this size and are well suited to threshing straw for thatching.

The correct setting of the drum–concave clearance is essential. It should be no smaller than is necessary to ensure the removal of grain from the ears. However, due to the transverse feeding of the crop, with the crop’s ears always orientated one way, some operators set the drum–concave clearance to be slightly smaller on the side of the machine that receives the ears and slightly greater on the side that receives the butt end of the stems. This potentially minimises mechanical damage to the straw but, given that one side of the drum and concave will be performing most of the threshing operation, it is potentially important to occasionally swap sides (in terms of both drum feeding and adjustments), to equalise wear across the threshing components.

Historically, agricultural contractors operated threshing machines, which were towed from farm to farm by steam traction engines. Once on-site, they were powered by the steam engine, driven via a long flat leather belt. Over time, tractors gradually replaced steam engines, but the flat leather drive belt has remained to the present day.

Despite its substantial size, a threshing machine does not have a high power requirement: typically 20 to 25hp for the popular 54in. (1.4m) wide machines. Once up to operating speed, the rotational inertia threshing cylinder and other rotating components create a ‘flywheel effect’, which tends to resist load fluctuations. Consequently, it is entirely feasible to drive a threshing machine from a suitably sized electric or hydraulic motor, dispensing with the long drive belt, which – under some circumstances – could be regarded as a safety hazard and which is difficult to guard effectively in practice.

Both the efficiency of threshing and the overall output of a threshing drum are very dependent on an even feed of crop material into the threshing mechanism. Intermittent feeding causes loss of output and a poorer grain sample. It also risks causing greater damage to the straw. This premise applies equally to modern combine harvesters.

Consequently, it is important to recognise that threshing is a flow process. It requires both a continuous feed of unthreshed material into the drum (more than 1,000 sheaves per hour) and continuous removal of the various processed and waste products (grain, straw, chaff and cavings). If using normal techniques, this requires a significant amount of manual labour (six to eight people), all engaged in handling materials, often working in dusty and unpleasant conditions.

Fortunately, much can be done to reduce the labour requirement associated with threshing and to improve the working environment of those remaining in the vicinity (*see* Section 5.1.3). Historically, threshing drum manufacturers offered a number of optional accessories to save labour and/or improve the speed and efficiency of threshing. Regrettably, these were not always selected by the customer.

Given the importance of consistent and relatively rapid feeding of the drum, one of the most useful accessories is the self-feeder (Figure 14). Essentially, it is a short canvas and slat conveyor assembly, which fits over the opening to the threshing cylinder. The person responsible for feeding the drum cuts the bonds of the sheaves and distributes the crop material over the conveyor, which then feeds it into the threshing mechanism. A series of power-driven, oscillating tines are mounted above the conveyor belt to further even out the flow of material. The self-feeder also improves the safety and the working environment of the operator feeding the drum. It prevents accidental contact with the revolving threshing cylinder, and greatly reduces emissions of dust and debris.

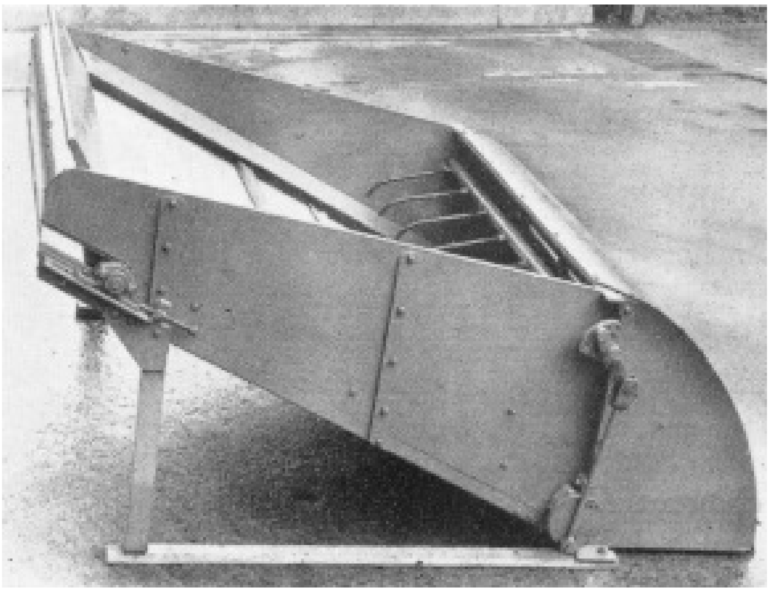

Figure 14: Threshing drum self-feeder. (Tullos Ltd)

The advantages and disadvantages of threshing LS using the Conventional method are as follows:

Advantages

- Tried and tested machine. Capable of good quality work.
- Good daily work rate (with sufficient supporting labour).
- Given the complexity and capability, a reasonably priced machine.

Disadvantages

- Very high manual labour requirement (six to eight people).
- Due to machine age and accrued working hours, requires considerable (specialist) out-of-season maintenance to ensure operational reliability.
- Very poor/non-existent availability of replacement parts.
- Quality and safety of operator's environment is questionable/poor.
- Machine production ceased 70 years ago. It is becoming harder to source second-hand machines. Market prices may well increase.

B. Reed comber (combed wheat reed)

An entirely different method of crop processing is used to produce CWR. While a threshing drum or some other form of threshing mechanism is still required, straw intended for CWR does not pass through the drum's threshing cylinder. Instead, it passes through a reed comber: a dedicated machine usually fitted on top of a threshing drum (Figure 15).

Within the comber, banks of tines arranged on a series of high-speed rotating drums literally comb the grain from the ears. They also remove all leaf material from the stems, leaving the stems straight and undamaged. The combed reed is then carried down from the top of the threshing machine between a series of conveyor belts, to be packaged – usually by a trusser. The combed-out grain, chaff, leaves and broken straw fall from the combing drums into the cylinder and concave of the threshing machine. Here, they receive further threshing and separation treatment, in the same way as when threshing LS: the main difference is that the volume of material that requires processing is considerably smaller.

Figure 15: Reed comber, threshing drum and trusser processing CWR.

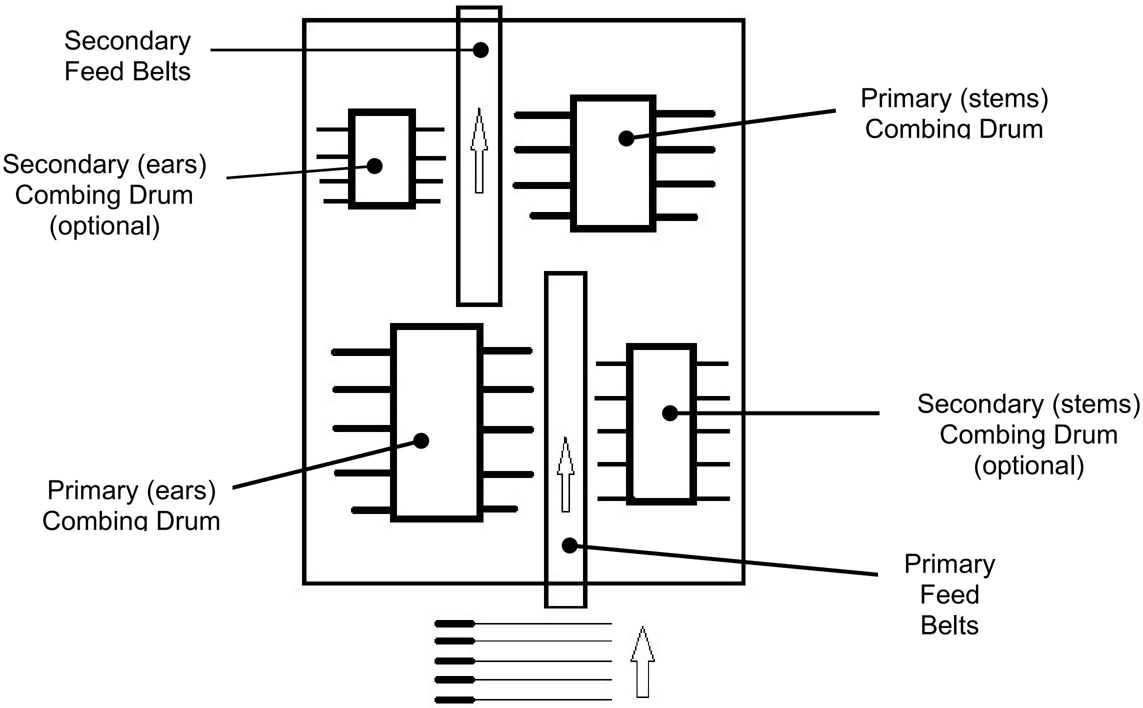

Figure 16: Reed comber: schematic layout.

Figure 17: Reed comber – primary feed (crop input) belts.

The reed comber operator cuts the bond from each sheaf and carefully feeds the crop in a horizontal layer into the machine, so that the plant stems are gripped between the primary feed belts that run between a series of spring-loaded rollers (Figures 16 and 17).

The operator controls the lateral position of the plant stems to ensure the crop ears are presented correctly to the primary combing drum, so they receive sufficient combing. Beyond the primary (ear) combing drum, the crop passes onto the secondary feed belts, which grip the stems at a higher point. This then permits the primary (stem) combing drum to remove all the leaf material from the lower section of the plant stems, before the combed reed exits the machine.

Reed combers are always fitted with at least two combing drums: one for combing the plant ears and one for the stems. However, some machines may be configured with three or even four drums. In such instances, the primary (ear or stem) drums may be partnered with a smaller, secondary combing drum (Figure 16), usually fitted with shorter and thinner combing spikes.

Using a greater number of combing drums undoubtedly increases the intensity of the combing action, and this potentially removes a greater proportion of (waste) material from the crop. However, it is unclear whether this would also result in the CWR receiving harsher mechanical treatment. In any case, in most instances, the combed-out/grain-free ears should remain intact on the plant stems after combing.

The CWR combing process has a lower rate of material throughput than LS threshing. This is partly because of the slower and more precise nature of crop feeding, and partly because a smaller proportion of the original crop material ends up in the final product. Nonetheless, the greater proportion of waste material created still requires handling and packaging (usually by a conventional baler). The manual labour required to operate a threshing machine-mounted reed comber is, therefore, slightly less than if the same (threshing) machine were processing LS. However, depending on the number of labour-saving devices employed, three to six workers would still be required.

Although the vast majority of reed combers are used in conjunction with a threshing drum, the latter only really acts in a supporting role. It provides mechanical drive to the comber and threshes/separates the combed-out grain, chaff and short straw. None of these roles directly affects the combing process or the quality of the CWR produced.

Consequently, for simplicity and convenience, some producers and/or combing contractors have constructed reed combers that operate in conjunction with (stationary) combine harvesters. These units may either be attached directly to the combine feeder housing, in place of the normal cutterbar table (header) (Figure 18), or may be standalone machines that feed the combed-out material into a (suitably modified) combine. In either case, a trusser (*see* Section 3.1.6) is usually integrated into the comber, to receive and package the processed CWR.

Figure 18: Bespoke reed comber (with integral trusser) fitted to a combine harvester.

In such instances (and also sometimes when using a threshing drum), a conveyor belt is arranged to transport the combed-out and threshed waste material from the rear of the combine or drum, directly to a conventional (small, square) baler for packaging. This saves labour and removes a person from a particularly unpleasant working environment.

The relative advantages and disadvantages of reed combers are very similar to those of threshing machines. Combers were only ever built in small numbers, and commercial production ceased more than 70 years ago. Consequently, the industry primarily relies on aged second-hand machines, which require considerable ongoing maintenance to ensure operational reliability. Nonetheless, these are appreciating in value.

While a reed comber is by no means a simple machine, its scale and relative lack of complexity does make new manufacture practicable: something that is not possible in the case of a threshing drum. Conscious of this opportunity, in the 1980s the Council for Small Industries in Rural Areas (CoSIRA) (subsequently the Rural Development Commission) prepared engineering drawings of an existing reed comber and made them available, to enable interested parties to self-manufacture machines. It is understood that a number of new reed combers have been constructed via this route.

The advantages and disadvantages of combing CWR using equipment associated with the Conventional method are as follows:

Advantages

- Tried and tested machine – capable of good quality work.
- Design drawings exist to enable replacement machines to be built – but not a simple or cheap exercise.

Disadvantages

- High manual labour requirement (three to six people, depending on the level of supporting equipment).
- Limited daily work rate. Not a particularly quick process.
- Old machinery – so requires good out-of-season maintenance to ensure operational reliability.
- No replacement parts available.
- Quality and safety of operator’s environment is questionable/poor.
- Original and newly built machines are becoming harder to source.
Market prices may well increase.

3.1.6 Crop packaging for onward sale

After threshing or combing, the LS or CWR is usually packaged to aid handling into store and/or for onward sale. To a degree, the packaging methods and equipment used depend on the product.

- **CWR** is packaged into string-tied bundles or trusses by a 'trusser' as the crop leaves the reed comber (*see* Figure 15). Following manual 'butting' on a flat surface to align the stem ends, the trusses are loaded manually into a hydraulically operated packaging cage. They are then compressed and string-tied into large cylindrical bundles/packs (*see* Section 3.1.4 A), Figures 21 and 22). These may be rolled short distances, but ultimately they require mechanical handling (*see* Figure 23).
- **LS** is usually packaged in an almost identical way to CWR, albeit without the butting process. The straw is discharged from the threshing machine directly into a trusser. The resulting trusses are then manually loaded into a packaging cage and formed into large, string-tied cylindrical bales for mechanical handling by forklift.

  Some growers use a low-density baler or 'buncher' in place of the trusser (*see* Figures 24 and 25). This machine gently compresses the straw into soft rectangular bales or bunches, which are then handled manually. Alternatively, with the provision of suitable guide rails, the action of the buncher can push the packages produced up and directly onto a stack or nearby trailer (*see* Figure 26), either for storage or onward transport.

A straw trusser forms bundles or trusses in virtually the same way as a binder packages sheaves (*see* Section 3.1.2). The main difference is that trusses are tied with two bands of (sisal) twine, whereas sheaves are tied with only one. In operation, the LS or CWR falls transversely into the machine's hopper, where a series of oscillating packing fingers gently compresses it against retaining arms and two pre-tensioned strands of twine. Once a sufficient weight/volume of material has been packaged, the knotting mechanism is automatically triggered, and the truss is tied and ejected onto the ground. A truss of CWR typically weighs approximately 14lb (6.4kg).

Trussers are usually standalone portable units (Figure 19), but they can be fitted to a threshing machine as an integral unit (Figure 20). In most instances, they are chain-driven from the threshing machine. However, for convenience and greater safety, some growers have converted machines to hydraulic drive (from a nearby tractor or hydraulic power pack).

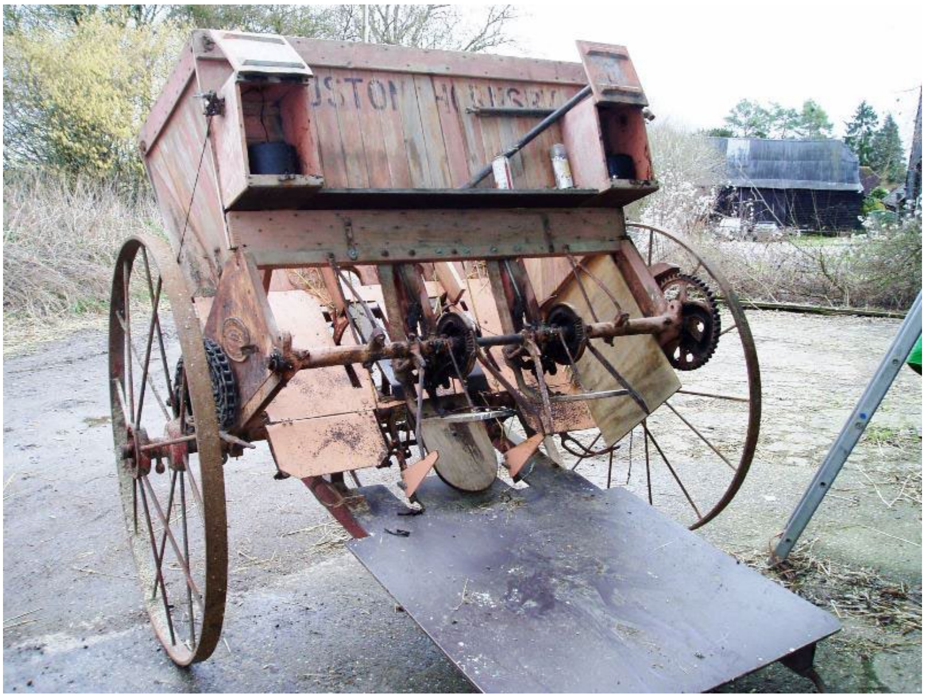

Figure 19: Hornsby portable straw trusser.

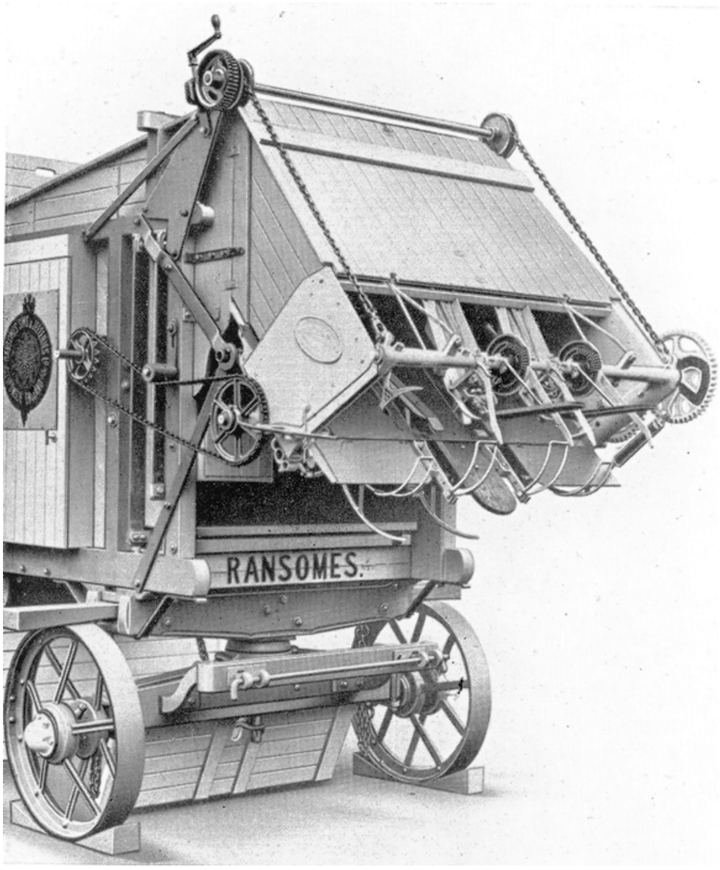

Figure 20: Integral Hornsby trusser installed on a Ransomes threshing drum.

Figure 21: Hydraulically operated packaging cage being loaded with CWR trusses.

Figure 22: Packs of CWR produced by hydraulically operated packaging cages. Wide and smaller diameter (left); narrower and larger diameter (right).

The dimensions and consequent capacity of hydraulically operated packaging cages vary between manufacturers. Smaller examples can accommodate 40 to 45 trusses of CWR, and so produce cylindrical packages weighing 250 to 300kg, whereas larger machines will accept 60 to 70 trusses and produce 330 to 400kg packs. Both pack diameter and width may vary between machines (Figure 22). Some growers market their product by weight, whereas others sell packs containing a given number of trusses. Additionally, the marketing approach followed may differ for CWR and LS, this frequently being producer-specific.

When packaging processed crop in a hydraulically operated cage, reinforced sheet steel sides are usually fitted to the cage to help produce a more consistent and stable package – of neater appearance (Figure 21). The stacking technique used depends somewhat on the cage width and product (stem) length, but the ends of the trusses must overlap in order to create a strong package that will withstand stacking and re-handling. If the crop is short and the cage is wide, a greater number of trusses are placed in the centre of the pack, to overlap those placed on the left and right (Figure 22, left). However, if the cage is slightly narrower and/or the crop is longer, fewer central/overlapping trusses are required (Figure 22, right). The packs produced by the cages are secured with heavy-duty polypropylene twine of the type used in large square balers. Most cages use five strands of twine, but some wider examples use seven.

Figure 23: Unloading packs of CWR at a work site.

Figure 24: Low-density baler packaging LS from a threshing drum.

A low-density or ‘swing-ram’ baler (or buncher) may be regarded as a halfway house between a trusser and a conventional square baler. Crop material is mechanically compressed by the action of a reciprocating ram, and the resulting rectangular bales or bunches are string-tied.

The action of a low-density baler is gentler on the crop than that of a conventional baler. The crop is not sliced into ‘wads’, and the density of the final package (when baling LS for thatching) is far lower: a 50in. (1.3m) wide bunch of LS typically weighs approximately 18lb (8.2kg). However, the action of a low-density baler is more aggressive than that of a trusser (*see* Figure 19), and the baler is not considered acceptable for packaging CWR.

The baler is usually belt-driven from the threshing drum, which feeds straw – preferably with stems orientated transversely – into the baler’s hopper (Figure 25). Packer fingers divide and transfer the crop into the upper part of the bale chamber. There, a reciprocating ram – travelling in a near-vertical arc – pushes the material down against that partly compressed by the previous ram stroke. Movement of the crop through the machine is restricted by squeezing the top and bottom surfaces of the bale chamber together slightly via turnbuckles. This increases resistance to crop movement through the chamber and the degree of crop compression achieved by the ram, thereby increasing the density and weight of the bales produced. Upon reaching the desired length, each bale is tied automatically with two strands of sisal twine.

Growers who use low-density balers instead of trussers to package threshed LS generally do not form the bales into larger packages for mechanical handling. Instead, they tend to handle the lightweight rectangular bales or bunches manually.

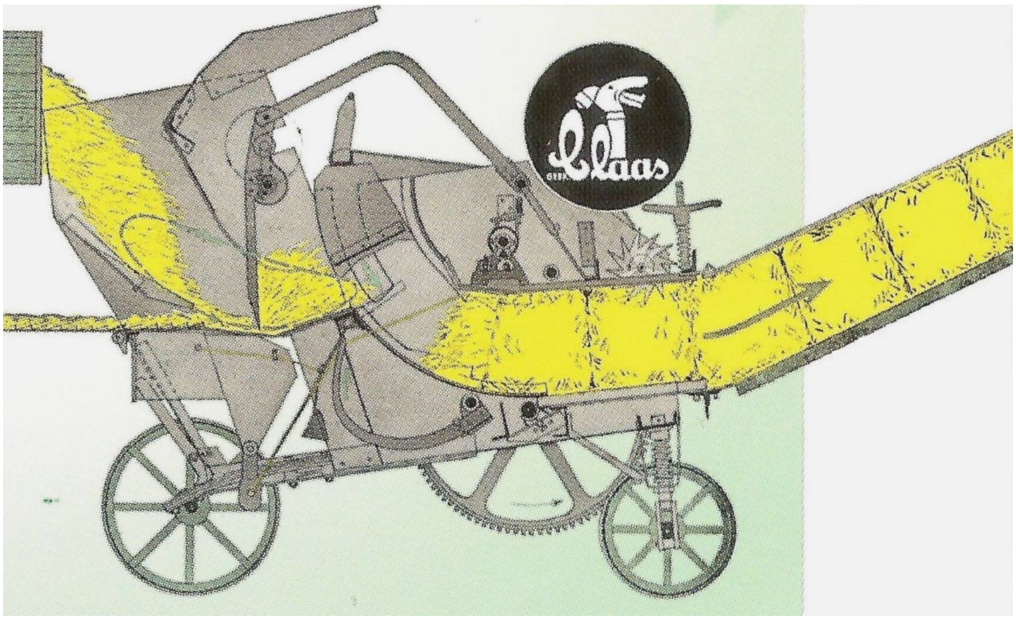

Figure 25: Claas low-density baler: cross-sectional view.

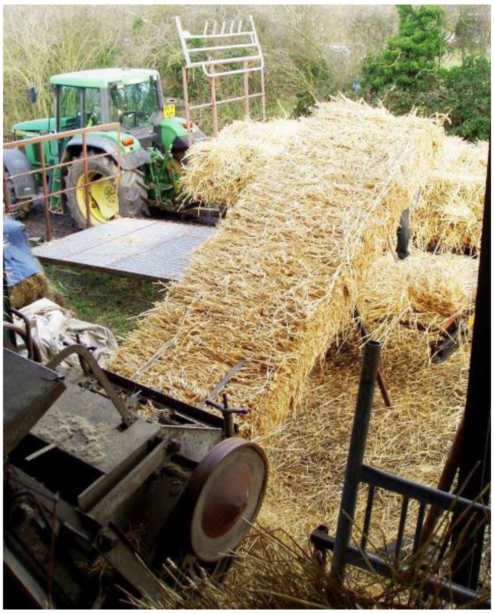

Figure 26: Low-density baler baling threshed LS and delivering bales onto a trailer.

In summary, the advantages and disadvantages of a trusser for packaging processed thatching straw are:

Advantages

- Tried, tested and relatively simple machine. Should be automatic in operation.
- Very gentle packaging action – minimal/no crop damage.
- Low-cost (old second-hand) machines still available, albeit in reducing numbers.

Disadvantages

- Trusses require forming into larger packages for efficient re-handling.
- Very old machine. Production ceased in early 1950s.
- Risk of poor machine (knotter) reliability due to machine age and accrued working hours, unless well-maintained.
- Very poor/non-existent availability of replacement parts.

By comparison, the advantages and disadvantages of a low-density baler are:

Advantages

- Should be completely automatic in operation.
- Can be configured to deliver bales onto a stack or a transport vehicle.

Disadvantages

- Less gentle packaging action than a trusser.
- Only wider chamber models (≥ 50in./1.3m) are suitable for thatching straw.
- Bales/bunches require forming into larger packages for efficient re-handling.
- Very old machine. Production ceased in the 1950s.
- Risk of poor machine reliability unless well-maintained.
- Poor availability of replacement parts.
- Machines are now becoming very difficult to source.

The relative advantages and disadvantages of (manually loaded) hydraulically operated packaging cages are discussed in Section 3.1.4 A.

3.2 Alternative (harvesting and processing) method

3.2.1 Overview

As described in Section 2.2, the generic characteristics of the Alternative harvesting/processing method is that, prior to any other operation, the grain is removed in-field from the standing straw. The straw is then cut, processed (if required) and packaged in-field, for transport to store or for onward sale. The operations and the exact equipment used varies between growers, and also depends on whether the intended end product is LS or CWR. The range of approaches encountered by this investigation are summarised in Figure 27.

An underlying feature of the Alternative method is that the grain and straw are harvested (separately) when the crop is at a more advanced stage of ripeness than would be the case for the Conventional method. However, the grain and/or straw may still not necessarily be fully ripe, as would be the case for commercial (agricultural) harvesting of grain on-farm: rather, the stripped and cut straw may still require a degree of further ripening, particularly during the early stages of the harvesting season. In certain circumstances, this may involve delaying in-field packaging for 24 or 48 hours after straw cutting and processing. More usually, it involves the in-field 'seasoning' of packaged (frequently round-baled) straw for a number of days prior to transport and storage within buildings. Round bales have a natural tendency to shed water and so – once packaged – the straw is protected to a degree.

Advantages of the Alternative method include high work rate/speed of operation, significantly reduced labour requirement, a much-improved working environment and far less risk of the straw spoiling if poor weather prevails during post-harvest ripening. Disadvantages include the higher cost (but not necessarily greater complexity) of the harvesting machinery, the possibility of exposing the crop to a greater risk of weather-induced damage pre-harvest and a possible higher risk of crop quality compromises. Opportunities for process improvements are discussed further in Sections 4 and 5.2.

3.2.2 Grain removal

The Alternative method of harvesting and processing straw for thatching relies on the removal of the grain from the standing crop by use of a stripper header attachment, fitted to a combine harvester in place of its standard cutterbar table (Figure 28). In this particular form, the stripper header is a relatively recent invention. It was developed at Silsoe Research Institute in the mid-1980s and was first made available commercially in 1990 by Shelbourne Reynolds Engineering Ltd.

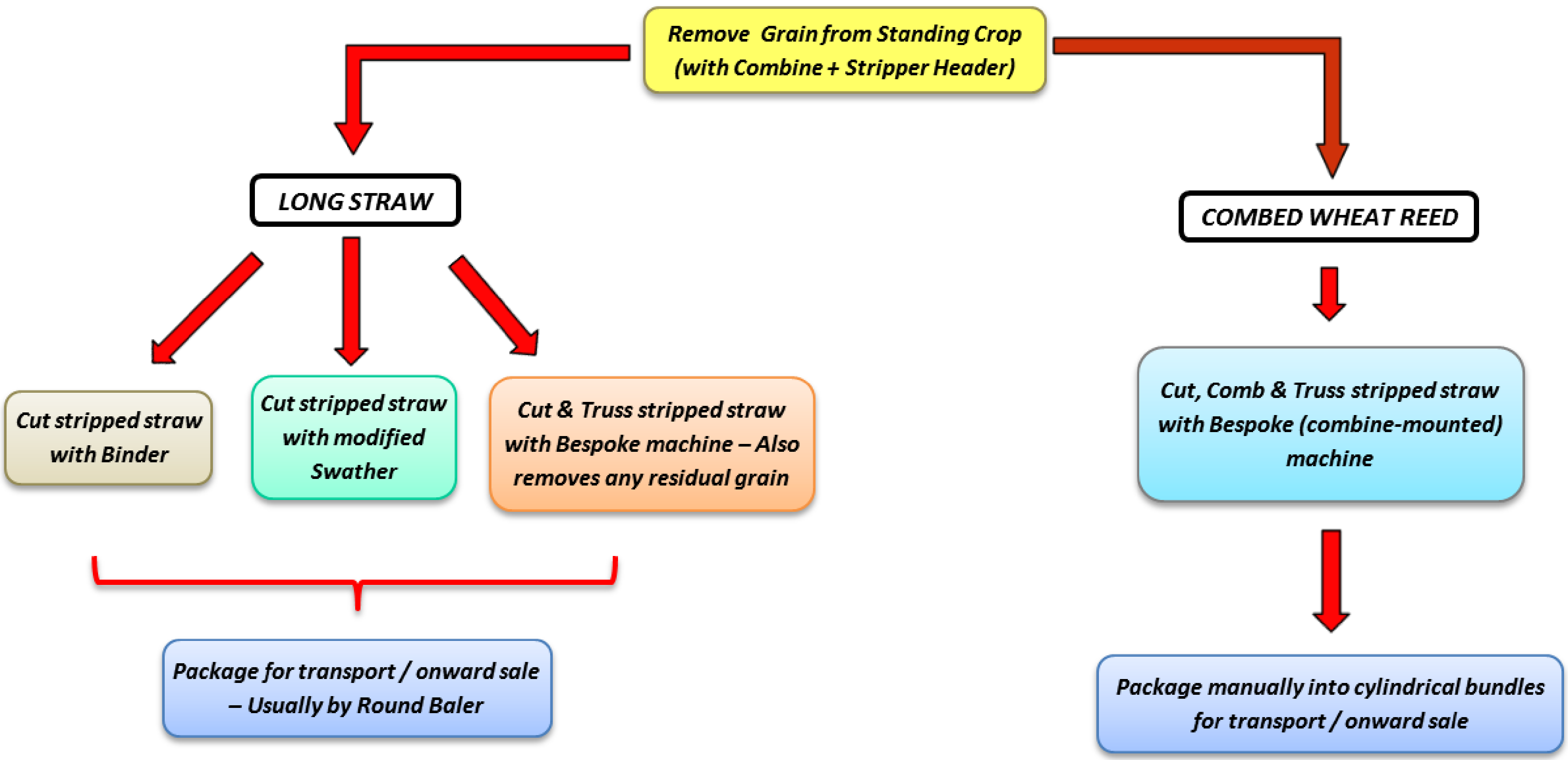

Figure 27: Typical activities performed when harvesting and processing thatching straw by the Alternative method.

However, the technique of harvesting cereals by removing the grain-containing ears from the standing straw is much older. Writing in the 1st century AD, Pliny described a harvesting machine used in Gaul. It consisted of a large comb attached to the front of a two-wheeled box cart, which was pushed along by an ox (Figure 29). The comb was run through the crop just below the ears, and a man walking beside the machine swept the heads backwards so that they were broken off and gathered into the box. A stripper header-based 'combined harvester' was subsequently developed in Australia in the mid-1800s, and machines of this type became extremely popular in that territory.

Figure 28: Grain removal from standing crop by combine fitted with a stripper header.

Figure 29: An artist's impression of Pliny's stripper harvester, *c.* AD 31. [Source: Gibbard 1997]

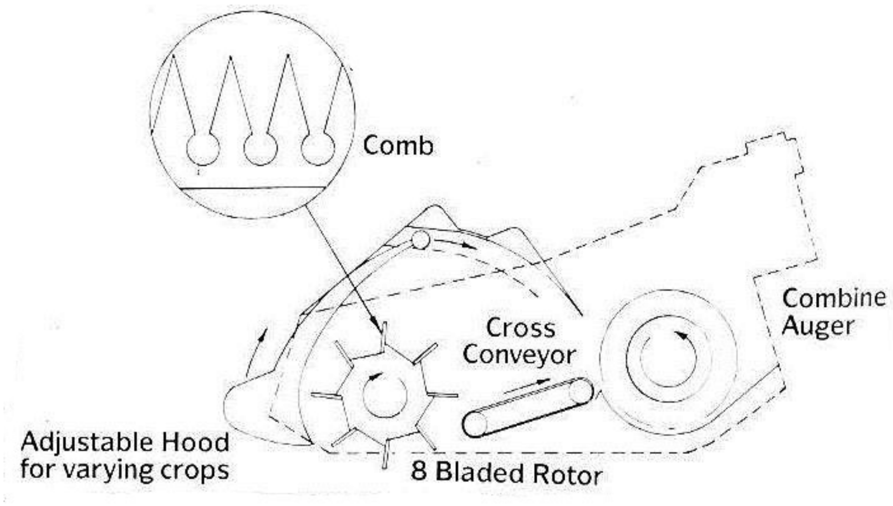

Figure 30: Stripper header: cross-sectional view. [Source: Culpin 1992]

The principle reason for redeveloping the stripper header in the 1980s, albeit as a specialist attachment for commercial combines, was that – when harvesting high-yielding cereals crops with a conventional (straw walker-type) combine – the process of separating grain from the large volume of loose straw passing through the machine ultimately limits combine work rate. When fitted with a stripper header attachment, only a fraction of the straw – together with the ears (that is, the grain and chaff) – enters the combine. This reduces the load on the threshing and separating mechanisms, thereby permitting far more efficient operation and higher output. However, on farms where the straw is utilised (for animal bedding, for example), an additional (straw) harvesting operation would be required.

Subsequent developments in combine threshing technology have significantly reduced the performance benefits originally offered by the stripper header. However, it remains popular for harvesting rice, grass seed and also cereals in regions where the straw is either of low volume or is regarded as a waste product. However, its unique mode of operation, namely removal of the grain from the standing crop, means it has a central role in the Alternative method for harvesting thatching straw.

The stripper header fits onto the combine in place of the standard cutterbar header (*see* Figure 28). An octagonal steel rotor, fitted with eight rows of keyhole-shaped stripping fingers or combs, extends across the width of the header (*see* Figure 30). In operation, the stripping rotor rotates backwards at relatively high speed (400–1,000 rpm) within an adjustable hood. The header is lowered sufficiently so that the front, adjustable, 'crop deflector' section of the hood just pushes against the crop ears and upper stems. The stripping fingers extend slightly lower and their rotation combs the grain from the ears.

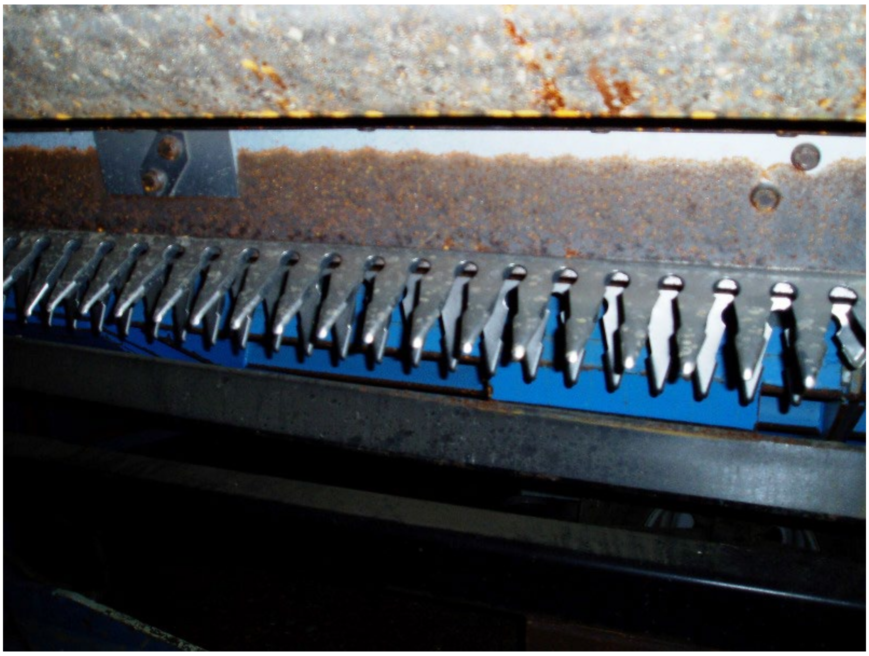

Figure 31: Stainless steel stripping fingers fitted to the rotor of a stripper header.

The stripped material, which during commercial cereal harvesting normally includes the grain-bearing ears and leaf material from the upper section of the plant, is transferred back to a conventional cross-auger and subsequently to the combine's threshing mechanism. The stripping action of the rotor itself is said to thresh at least 85 per cent of the grain from the ears prior to any further threshing within the combine. However, during harvesting of commercial grain crops, it is usual practice to adjust a stripper header to remove the majority of ears from the plants and pass them through the combine. This allows the threshing mechanism to recover any residual grain that the stripping rotor has failed to thresh out.

When the stripper header was originally marketed in the UK, its keyhole-shaped stripping fingers were made of polyurethane plastic. However, later versions use stainless steel fingers (Figure 31), which feature a rounded-edge profile on one surface and a cup-shaped profile on the other. By changing which side of the fingers contacts the crop, and also by altering the rotor speed, the aggressiveness of the stripping action can be varied.

When using a stripper header to remove grain from straw intended for thatching, a compromise is required between a sufficiently aggressive stripping action (to maximise grain removal and minimise residual grain left in the ears) and a gentler action (to minimise ear removal and mechanical damage to the upper section of the plant stems). Many different parameters have an influence on these operational characteristics, including stripper rotor speed, rotor height setting, crop deflector position, combine forward speed, crop type, crop maturity and the prevailing weather conditions.

In normal/damper harvesting seasons, the majority of stripped/threshed-out ears remain attached to the plant stems, whereas in drier conditions the degree of ear removal is significantly greater. Interestingly, the physical process of grain removal by a stripping rotor is extremely similar to that employed by a reed comber (*see* Section 3.1.5 B) and the resulting appearance of the stripped or combed-out ears is also very similar. It is often said that there are very few fundamentally new inventions in agricultural engineering!

A stripper header can, of course, only remove grain from the ears that come into contact with its stripping fingers. Newer crop varieties tend to grow to a more even height, whereas the ears of older varieties may grow to a range of heights. Due to the need to limit the degree of mechanical damage to the straw, it is not always possible to operate the stripping rotor at a sufficiently low height to recover grain from the lower ears. Consequently, stripper headers operate more effectively in crops of even height. They are also understood to be particularly effective for harvesting triticale: a crop which can sometimes be more difficult to thresh (rather than to comb) by conventional combine harvesting methods.

Grain harvesting by stripper header is quite a fast process: much quicker than the subsequent processes of straw cutting and/or processing. The forward speeds used are considerably higher than those employed during conventional combine harvesting and, when combined with header working widths of up to 32ft (9.6m), these generate high work rates. It is, therefore, possible to harvest the grain quickly when conditions are ideal.

Unfortunately, the passage of the stripper header tends to bend the crop stems forwards slightly, and, in addition, a proportion of the stripped straw is run down by the combine’s wheels, which tend to be quite wide. These problems can be mitigated by careful planning of the in-field harvesting technique, ensuring that the subsequent straw cutting operation is performed in the opposite direction to that of the stripping operation. This can permit almost all of the trafficked straw to be recovered from the combine wheelings. Use of wider headers also reduces the proportion of wheeled straw. Straw recovery from the wheelings is more effective if the stripped straw has not been rained on prior to the subsequent straw cutting/harvesting operation.

To avoid straw damage from the combine wheels, some growers offset the stripper header entirely to one side of the machine, and then cut and remove the stripped straw immediately – before the next pass of the combine around the field. Unless this approach is taken, it must be accepted that either a proportion of the straw may not be recoverable, or that it will be harvested but will have been subject to a degree of bruising by the combine’s wheels.

The advantages and disadvantages of using a stripper header to remove grain from straw intended for thatching straw include:

Advantages

- Very high work rate. Can cover ground quickly and remove the grain at the desired level of crop maturity.
- Modern, commercially available machine.
- Good replacement parts availability.
- One-man operation (combine driver).
- Excellent operator's environment (combine cab).
- Very effective at removing grain from triticale.

Disadvantages

- Stripper headers are expensive, unless purchased second-hand.
- Requires a combine harvester as a 'base vehicle'. A degree of additional cost and complexity, but cheaper second-hand examples are perfectly adequate.
- Will potentially leave some residual grain in any part-threshed or lower height ears that remain on the plant stems.
- Leaf material is removed from the upper section of the plant stems. (Not an issue for CWR production).
- A proportion of straw is run down and bruised in the combine wheelings. May or may not be recoverable, depending on the subsequent straw harvesting technique used.
- Crop is harvested slightly later than when using the Conventional method. Stands longer in the field and so may be at slightly greater risk of damage from weather-induced lodging.
- Considered by some growers to be more suited to the drier harvesting conditions and larger flatter fields typically found in East Anglia and the South East.

3.2.3 Straw cutting and (in-field) crop processing

Following grain removal by stripper header, a range of options exist for harvesting the standing straw. However, it is important to appreciate the circumstances under which this operation must be performed. As previously mentioned, it is very likely that a proportion of the (stripped) straw will have been run down by the combine's wheels. Additionally, due to the necessary compromise between an aggressive stripping action for effective threshing and limiting mechanical damage to the straw, in order to maintain product quality, a high proportion of the crop ears will probably remain attached to the plant stems.

As previously discussed, the stripping action alone is unable to remove much more than 85 per cent of the grain from the standing ears. Consequently, some residual grain can be expected to remain attached to the straw.

Some Alternative harvesting methods include additional in-field processing treatments to remove this residual grain prior to packaging, whereas others do not. As shown in Figure 27, the range of available options depends partly on the product type (LS or CWR) and partly on grower preference (see below):

Long straw

Option 1: Cut straw – No further processing – No intermediate packaging.

Option 2: Cut straw – No further processing – Form into intermediate packages (sheaves).

Option 3: Cut straw – Further processing to remove residual grain – Form into intermediate packages (sheaves).

Combed wheat reed

Cut straw – Further processing to remove both residual grain and plant leaf material – Form into intermediate packages (trusses).

Fundamentally, the major advantages of (in-field) crop processing by any of these methods is that little or no manual handling of the product is required. The working environment is far superior to that associated with Conventional processing methods and, in every instance, the risk of weather-induced crop spoilage during in-field ripening (in stooks) is significantly reduced, due to the virtual removal of this element from the harvesting process.

Figure 32: Adapted self-propelled swathing machine (swather) windrowing stripped wheat straw.

A. Long straw (Alternative method)

Figure 32 shows LS being cut and windrowed (placed in swaths) by the Option 1 method. An adapted self-propelled swathing machine cuts the straw and delivers it to one side of the cutterbar via a conveyor belt. As the crop leaves the conveyor, a series of air jets attempt to reorientate the plant stems so they lie transversely rather than longitudinally (that is, cross-wise instead of length-wise) in the swath. The straw is subject to no further treatment or intermediate packaging before being packaged for transport to store and onward sale (*see* Section 3.2.4 A).

Given the swather's 18ft (5.5m) cutting width and quite a high forward speed, this straw harvesting approach can potentially deliver a very high daily work rate. However, the investment required to both purchase the (second-hand) machine and then adapt it for this particular purpose is considerable. It is possible to use a binder (with the sheaf-forming and tying mechanism deactivated) to cut a straw crop and form it into swaths or windrows. However, while the capital investment would be significantly less, the daily work rate would be lower. The machine would also require some form of modification to reorientate the cut stems cross-wise in the swath. Some growers are known to have implemented such modifications with success.

The Option 2 method of cutting stripped LS has much in common with the Option 1 technique. The key difference is that a binder, or a modern derivative thereof, is used to cut the straw and package it into sheaves. Under normal circumstances, these do not require stooking because the straw has been stripped and cut at a more advanced stage of ripeness than would be the case if following the Conventional harvesting approach. Nonetheless, the sheaves do require further manual handling before being packaged for transport/onward sale.

The Option 3 method subjects the stripped LS to more comprehensive treatment, but this is still performed in-field by a single, bespoke, tractor-drawn machine (Figure 33). This impressive farm-built machine in effect combines the functions of a binder with some of a reed comber. The previously stripped straw is cut by a cutterbar and reel assembly reminiscent of a binder. It is then conveyed sideways and upwards between a pair of conveyor belts that transfer it between a further pair of belts, similar to the crop intake belts of a reed comber (*see* Figure 17). These grip the plant stems and convey the crop laterally, while the upper ends of the stems and any partly threshed ears are combed by a rotating combing drum to remove any residual grain (which falls into a hopper underneath the machine). The processed straw is then transferred to a binder-type knotter deck, bound into sheaves and ejected onto the ground.

Figure 33: Bespoke tractor-drawn machine for cutting and binding stripped LS. It also removes residual grain from unthreshed or missed ears.

It is difficult to draw direct comparisons between the three options for harvesting previously stripped LS because they do not perform exactly the same functions. However, their relative advantages and disadvantages may be summarised as follows:

Option 1 (swather)

Advantages

- High work rate. Can cut straw quickly at the desired level of maturity.
- One-man operation.
- Excellent operator's environment.
- No manual handling of the crop.

Disadvantages

- Expensive machine to purchase and adapt.
- Questionable spare parts availability.
- Precision of crop (plant stem) orientation in swath could perhaps be improved.

Option 2 (binder)

Advantages

- Less costly machine (than a self-propelled swather).
- Possible/probable one-man operation.

Disadvantages

- Lower daily work rate (than a self-propelled swather).
- Poor/non-existent spare parts availability (unless a modern binder).
- Further manual handling of sheaves required before packaging.

Option 3 (bespoke machine)

Advantages

- Combines all tasks and removes any residual grain.
- Potential higher quality end product.
- One-man operation.

Disadvantages

- Lower daily work rate (than a self-propelled swather).
- Bespoke machine. Requires considerable design and construction effort.
- Spare/replacement parts must be self-manufactured.
- Further manual handling of sheaves required before packaging.

Figure 34: Combine-mounted reed comber and trusser harvesting stripped cereal straw.

B. Combed wheat reed (Alternative method)

During this investigation, only one grower was found to be harvesting and processing CWR by the Alternative method.

As illustrated in Figure 27, after grain removal by use of a stripper header (*see* Figure 28), the standing straw is cut, combed and packaged in trusses by a bespoke combine-mounted machine (Figure 34).

This farm-built machine has much in common with the LS cutting and processing machine shown in Figure 33. However, it is slightly more complex insomuch as, following cutting by a 7ft (2.1m) cutterbar and reel assembly, the stripped straw is conveyed sideways and upwards into a twin-drum reed comber.

The latter is of a conventional configuration with two pairs of crop feed belts and two (primary) combing drums responsible, respectively, for removing residual grain and any remaining leaf material from the top of the plant stems, and all leaf material and short straw from the lower parts of the stems.

The combed-out material falls into a hopper and is conveyed into the combine's threshing mechanism. However, unlike a conventional reed comber, the vast majority of grain has already been removed by the preceding stripping operation. The combed straw then passes directly to a two-string trusser, where it is packaged, tied and ejected.

Putting to one side the (possibly contentious) issues of product characteristics and acceptability, the processing of CWR by the Alternative method appears to have the following advantages and disadvantages:

Advantages

- All crop processing operations performed in-field. All plant leaf material and any residual grain removed in-field.
- Excellent operator's environment (combine cab).
- Minimal labour requirement – one-man operation (combine driver).
- No manual handling of the crop (unless stooking required).
- Good work rate – similar to that of a binder, but larger growers will probably require multiple machines.
- Severity of mechanical treatment of straw (resulting from use of a stripper header and this machine) is comparable to that of a conventional reed comber.

Disadvantages

- A proportion of straw is likely to have been trafficked by the combine's wheels.
- Bespoke machine. Requires considerable design and construction effort.
- Requires a combine harvester as a base vehicle, so incurs additional cost and complexity.
- Poor/non-existent spare parts availability (but can self-manufacture replacement parts).
- Early in the harvesting season, the trussed CWR will potentially require further drying (stooking) before packaging for onward sale.

3.2.4 Crop packaging for onward sale

As illustrated in Figure 27, the approaches and associated equipment used for packaging Alternatively harvested thatching straw for onward sale largely fall into two groups, depending on the product type (LS or CWR). This investigation found the processed straw was either packaged in large round bales or medium to large bundles. LS can accommodate a degree of mechanical bruising during harvesting/processing and packaging, but CWR is usually deemed to require more gentle treatment. Consequently, a different packaging approach is usually employed.

It is important to appreciate that Alternatively harvested straw is unlikely to be completely dry at the time of processing or immediate in-field packaging. Some moisture is usually still present in the stems, and this must be allowed to disperse before final storage. This may occur during a suitable (for example, 24-hour) delay between intermediate and final packaging or, if the straw is round-baled, by allowing the bales to stand outside to condition for 48 to 72 hours before final transportation and storage.

A. Packaging long straw (harvested by the Alternative method)

Where LS is harvested using the Alternative method, and has been packaged into sheaves following grain removal and any additional processing (Options 2 and 3), the straw is further-packaged in-field using a large round baler. This process is described in Section 3.1.4 C, and involves the sheaves of stripped straw being formed manually into swaths to permit baling, each sheaf being laid transversely, head-to-tail relative to its neighbour.

Even though the stripped ears no longer contain grain, depending on the natural (variety and crop type-dependent) taper of the plant stem, the head-to-tail arrangement of the sheaves is necessary to avoid the formation of conical rather than cylindrical bales. Swath preparation and baling must be performed with care, to avoid undue straw damage because, as previously mentioned, the bale chambers of most round balers are only 4ft (1.2m) wide, which leaves little room to spare when attempting to bale 3 to 4ft (1.0–1.2m) tall sheaves.

Fixed-chamber round balers (*see* Figures 10 and 35, right) appear to be preferred for the (round) baling of stripped sheaves, mainly due to their ability to create a bale with a soft core and a denser outer shell. The completed bales are secured with polypropylene netwrap before being discharged from the baler.

Growers have commented that bale formation must be a relatively quick process and, particularly when using a fixed-chamber baler, is often a compromise. If the crop intake rate is low and the bale formation process takes too long, there is a risk of excessive mechanical damage to the material. Conversely, if the crop intake rate is too high and causes the bale to be formed too quickly, crop damage will be minimised, but the bale may be insufficiently dense for stable transport and storage.

Round balers are also used for the final packaging of stripped straw that has been cut with a self-propelled swather (Option 1, *see* Section 3.2.3). In this instance, the stripped straw has not been packaged prior to baling, but has simply been placed in a windrow by the swather (*see* Figure 32). Air jets located at the end of the swather's cutting table attempt to reorientate the plant stems so that they lie transversely (cross-wise) in the swath, rather than longitudinally. However, it is unclear exactly how well this objective is met. The swath is then picked up and packaged by a variable-chamber round baler (Figure 35, left), rather than a fixed-chamber machine. Once again, the completed bales are secured with polypropylene netwrap.

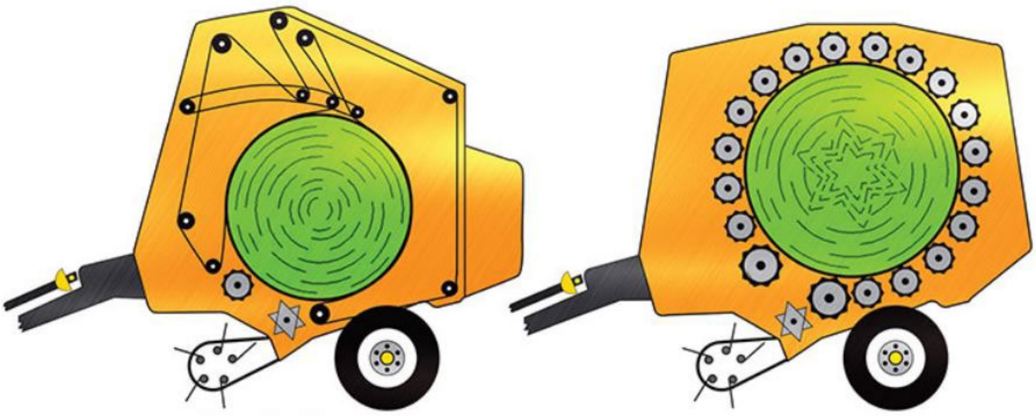

Figure 35: Different types of large round baler: variable chamber (left) and fixed chamber (right).

The relative advantages and disadvantages of using round balers for the final packaging of Alternatively harvested long straw are:

Advantages

- High daily work rate (20–30 acres/8–12ha, plus).
- Readily available machine, both new and second-hand.
- Good spare parts availability.
- Given the complexity, a reasonably priced machine.

Disadvantages

- Manual labour required to form swaths for the baler (Options 2 and 3 only).
- Crop (temporarily) at greater risk of weather damage when laying in swaths.
- Requires careful (baler) operation.
- Risk of damage to straw. Requires careful swath preparation.
- Bales need to remain outside for 48 to 72 hours to sweat/condition before final storage.

B. Packaging combed wheat reed (harvested by the Alternative method)

The sole grower found by this investigation to produce CWR using the Alternative method (*see* Section 3.2.3 B) utilises a dedicated mobile in-field packaging facility (Figure 36). This is used to package the trusses produced by the combine-mounted reed comber into medium to large cylindrical bundles.

Trusses of stripped and combed CWR are manually loaded into compartments on a bespoke tractor-drawn trailer. When enough have been collected, they are compressed and bound with a number of steel bands, of the type used for industrial packaging. The completed bundles/bales, which each contain approximately 18 to 20 trusses of CWR, are then discharged back onto the field to await collection and transport by telehander and trailer (*see* Figure 6).

Although an entirely manual process, the equipment used has been refined to permit rapid and convenient operation, and can achieve relatively high work rates. A team of six workers (three loading and three binding) can clear 20 acres (8ha) in a good day.

Figure 36: Manual packaging of CWR trusses into large cylindrical bundles/bales in a dedicated mobile packaging facility.

The advantages and disadvantages of using this particular method and equipment for the final packaging of Alternatively harvested CWR are:

Advantages

- Good daily work rate. Worker productivity maximised.
- Simple, robust and relatively cheap machine. Designed and built on-farm.
- Minimal spare parts requirement.

Disadvantages

- High manual labour requirement (six people).
- Crop (temporarily) at risk of weather damage while awaiting packaging.

4. Scope for efficiency improvements

4.1 Requirements and limitations

The primary aim of this investigation is to identify appropriate mechanisation solutions that may make thatching straw production more efficient, sustainable and economically viable. When considering the scope for operational efficiency improvements in machinery used for harvesting and processing thatching straw, it is important to recognise the constraints likely to be imposed on any potential mechanisation solutions. Ideally, any equipment and solutions must satisfy the following requirements:

- Save time and money.
- Not be detrimental to product quality.
- Suit the needs of the grower, in terms of work rate, complexity, ease of use and reliability.
- Be economically viable.
- Integrate (where possible) with other (existing) harvesting and processing techniques, without their significant modification.

Historic England surveys (Stradling et al) suggest that there are currently about 60 growers of thatching straw in the UK. Approximately 40 per cent of these grow more than 60 acres (24ha) of straw (Figure 37) and, collectively, they account for more than 80 per cent of the total straw area currently grown. This is not to suggest that mechanisation solutions should be biased towards larger growers: 60 per cent of thatching straw growers still grow less than 60 acres of straw annually. Rather, it does highlight that potential mechanisation solutions must be found to suit both smaller and larger growers.

Due to its very specific requirements and the very small number of potential customers, the market for machinery to harvest and process thatching straw is both small and niche. It is, therefore, very unlikely to attract dedicated commercial products at an economically viable cost, unless such equipment can also be utilised in other markets for other purposes.

This viewpoint is confirmed by the lack of commercially produced equipment available today. Instead, it appears the majority of growers, large or small, are currently using either old, second-hand agricultural machinery, adapted where necessary to suit, or home-designed, bespoke equipment engineered specifically for the intended purpose. Bespoke machinery may require a greater initial investment but, if it is designed and constructed appropriately, may deliver greater productivity and improved reliability in the longer term.

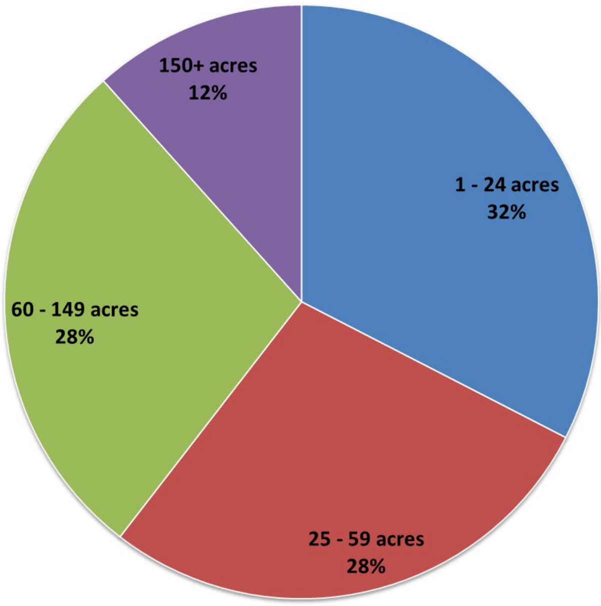

Figure 37: Breakdown of UK thatching straw growers according to crop area grown. [Source: Stradling]

As discussed in Section 2.2, at present approximately 80 per cent of thatching straw is harvested and processed by the Conventional method. However, this method faces the greatest challenges and, consequently, requires appropriate mechanisation improvements if straw production by this technique is to remain commercially viable (*see* Section 4.2). Fortunately, the Conventional method offers the greatest scope for improvements, both in terms of operational efficiency and in many other respects.

To a large extent, growers who employ Alternative harvesting and processing methods have already taken the initiative and implemented appropriate mechanisation solutions to improve the efficiency of their operations. However, this is not to suggest that further improvements could not be made, albeit perhaps to further enhance product quality.

There remains considerable debate among thatchers regarding the relative superiority of straw produced by the Conventional or Alternative method. Some are suspicious, and perhaps even dismissive, of the straw harvested and processed by the Alternative method; others regard it as perfectly acceptable.

Both Conventional and Alternatively harvested products are well-established in the marketplace, and neither seems likely to be displaced. Indeed, the latter is arguably an evolutionary development of the former. However, while the Conventional harvesting approach currently dominates UK thatching straw production, and is likely to continue to do so, the mechanisation systems and equipment used by it are, unquestionably, in greatest need of revision/improvement – but only if this can be achieved without detriment to product quality.

4.2 Crop harvesting and processing issues

The vast majority of the challenges concerning the harvesting and processing of thatching straw, which may potentially be addressed by appropriate mechanisation solutions, are associated with the Conventional method. The Alternative harvesting approaches implemented by some growers have already addressed many of these key issues, but further scope for improvement still exists within this area.

The crop harvesting and processing techniques and equipment employed by the Conventional method are similar, if not identical, to those once used for the commercial harvesting of cereals in the UK, prior to the introduction of the combine harvester. The primary reasons the combine harvester displaced the binder and threshing drum were the significant saving in labour and the operational efficiency improvements it offered.

During 1959–60, when binders were still in widespread use in East Anglia, the Farm Economics Branch of Cambridge University surveyed the labour requirement(s) for harvesting cereals by the binder and threshing drum method (Table 2) – in essence the Conventional method of harvesting and processing thatching straw.

Table 2: Labour requirement for harvesting cereals by binder and threshing drum. [Source: Culpin 1968]

Operation	**Labour input** (Man hours per acre)
Cutting corn (by binder)	2
Stooking	4
Carting and stacking	8
Threshing	8
Total for harvesting	**22**

These data support the findings of this investigation. They show that grain removal by threshing drum (or, indeed, by reed comber) is a slow and labour-intensive activity. This is largely due to the number of people required to operate the equipment, most of whom are involved in the feeding or removal of crop material to/from the machine.

The Cambridge University study also highlighted that a significant labour requirement was associated with stooking, but more especially with the gathering and transportation of the crop from field to store. Consequently, in the context of harvesting thatching straw, any mechanisation solutions that can reduce labour requirement and improve efficiency in these particular areas will be especially beneficial.

By comparison, cutting the crop by binder appeared to be a relatively efficient operation. No doubt it would be even more efficient if only a single operator were required (the values reported suggest both a tractor driver and a binder operator were present).

This investigation surveyed the general mechanisation issues and operational difficulties experienced by 22 thatching straw growers. These issues were primarily (but not exclusively) associated with the Conventional harvesting and processing method and, with regard to manual labour requirement, corresponded with the findings of the Cambridge University study.

The general mechanisation issues and operational difficulties experienced at present include:

- High manual labour requirement and/or poor labour availability.
- Limited machine work rate, leading to poor productivity per worker.
- Old/unreliable machinery.
- Ongoing (specialist) maintenance requirement (for old and/or specialist machines).
- Poor spare parts availability (due to old and/or specialist machinery).
- Poor worker operating environment (mainly in relation to Conventional crop processing equipment).
- Poor machine guarding and sub-optimal operator safety.

Possible options to address certain of these issues are discussed in Section 5.

5. Possible mechanisation options/improvements

5.1 Conventional harvesting method

The Conventional method of harvesting and processing thatching straw undoubtedly presents the greatest opportunities for improving efficiency and overall cost reduction, by the implementation of appropriate mechanisation solutions. In many instances, individual growers have already made improvements, but there remains a great deal more that can be done to address the issues raised by many growers. This may simply involve the dissemination of recommendations to improve the operation of existing machinery, but there is also scope to modify existing equipment or even to develop new machinery to address specific problems.

The areas of greatest potential opportunity for improvement are those that currently are labour-intensive and/or involve a poor working environment. They include:

- In-field crop handling (in relation to crop ripening and stooking).
- In-field crop packaging (for transport to store).
- Crop processing (concerning crop transfer and overall labour requirement).
- Crop processing (to improve operator working environment).

However, opportunities for improvement also exist regarding the following operations:

- Crop cutting.
- Crop packaging after processing.

It is intended that Phase 2 of this study will explore the feasibility of the mechanisation options identified by Phase 1, and will review the opportunities for implementing the most promising examples. However, in the meantime, the following subsections provide a brief overview of some of the potential opportunities for system improvements and/or further mechanisation.

Please note that, for convenience, these are presented in the order of the normal crop harvesting sequence, rather than in order of perceived benefit.

5.1.1 Crop cutting

Potential opportunities to improve the efficiency and reliability of the Conventional crop cutting process include:

- Conversion of (existing) binder cutting mechanisms to use commercially available (combine) cutterbar components.
    - Many growers have already done this, but scope exists to disseminate information regarding viable approaches, components to utilise and possible sources of supply.
- Replacement of (old/worn/unreliable) binder knotter mechanisms with commercially available knotter units from conventional balers.
    - Again, many growers have already made such modifications, but it would be beneficial to disseminate suitable technical guidance and recommendations to a wider audience.
- Replacement of (binder) crop conveying canvasses with suitable synthetic conveyor belting materials. Provision of (technical) guidance regarding approaches and materials to use and possible sources of supply.
- Migration to (imported) tractor-mounted designs of reaper–binder.

(Imported) tractor-mounted reaper–binders

Seemingly identical variants of this reaper–binder machine (Figure 38) appear to be produced by manufacturers in Italy, India and Turkey. However, examples are imported by an established UK agricultural machinery manufacturer.

The PTO-powered machine is carried by the tractor's rear 3pt. linkage, and its offset 4½ft (1.4m)-wide reciprocating cutterbar runs beside the left-hand rear wheel. The cut crop is gathered by a series of collecting fingers, maintained in a vertical orientation and transferred to a central feed passage. Here, it is packed and tied into sheaves before being conveyed, still in a vertical position, across the rear of the tractor and discharged to the ground, nominally in line with the vehicle's right-hand rear wheel. This ensures the cut crop is not trafficked by the tractor during the next pass around the field.

The machine is basic in construction, but is in widespread use around the world (for cereal harvesting), and a number of examples are already used by UK thatching straw growers. The cutterhead assembly is also used with apparent success on pedestrian-controlled machines from the same manufacturers. These are commonly used for cutting water reed in the UK.

Figure 38: Tractor-mounted reaper–binder. (BCS - Alvan Blanch)

One notable drawback of this machine when harvesting thatching straw is the inability to adjust the height at which the band is tied on the sheaf – this being a convenient operator adjustment on conventional binders. This may not be an issue in crops of consistent growing height, but older wheat varieties are more prone to height variation. Consequently, this aspect of the machine may require modification if wider uptake is desired.

The UK importer currently installs additional safety guarding to satisfy UK/EU essential health and safety requirements, and performs the obligatory CE or UKCA marking and declarations. At the time of writing (spring 2023), the list price of the machine is understood to be in the region of £10,000. Given that second-hand conventional binders may be readily obtained for £500 to £1,000, the cost and current capability of this machine may be unattractive to some growers.

5.1.2 In-field crop handling and packaging

For the Conventional harvesting method, this is one of the areas with the greatest potential for improvement. The following proposals are based on the assumption that stooking will remain the principle method by which thatching straw is ripened in-field. At present, this seems very likely. However, some growers are experimenting with the ripening of straw in windrows. It remains to be seen whether this technique, which avoids stooking and simplifies subsequent mechanical packaging and handling, will become more widespread.

Possible opportunities to improve the efficiency, cost-effectiveness and reliability of the crop handing and packaging processes associated with (Conventional method) in-field crop ripening include:

- Machine modifications – and operational guidance – to enhance the performance of (commercial) balers when packaging sheaves, and to reduce crop damage.
    - Many growers have already modified their balers, often in very similar ways, but scope exists for wider dissemination of this information.
- Sharing of information concerning potential sources of replacement spares and machine service technicians for specialist (vintage) balers.
- Development of sheaf collection devices for use with binders.
    - Sheaf carriers never found widespread popularity in the UK, but the advantages they offer in terms of improving the efficiency of the subsequent stooking process are well documented. Perhaps this basic technique for sheaf grouping should be revisited.
- Development of an effective automatic stooking device for binders.
- Exploration of the scope for developing self-loading mechanisms for hydraulically operated packaging cages (cradles).
- Exploration of the scope for developing self-knotting mechanisms for hydraulically operated packaging cages (cradles).
    - If packaging cages are loaded manually, usually by a team of workers, the time taken to tie the securing strings may seem of little consequence. But if the cage is loaded mechanically – as part of a flow process – less time will be available to complete the tying operation. Also, manual intervention may be undesirable and even, potentially, unsafe. Automatic knotting could be a cost-effective upgrade to existing machines.

Automatic stooking (or shocking) machines

The concept of automatic stooking is far from new. A significant number of machines were designed and patented in North America during the early 1900s. A number were commercialised and used on farms; some examples even reached the UK. The automatic stooker was designed to be either an integral part of the binder or (more usually) a separate machine to be used in conjunction with existing binders (Figure 39). Their purpose was to remove the need for labour to stook the crop, and it seems they were effective in this respect.

However, the rapid and widespread adoption of the combine harvester in the grain-growing regions of North America during the 1920s effectively made the binder, threshing drum and newly launched automatic stooker obsolete. It is suspected that smaller US growers, who did not use combine harvesters, had no need for automatic stooking. With smaller fields and a plentiful labour supply, their position was no doubt similar to that of UK growers. In any case, automatic stooking was consigned to the history books.

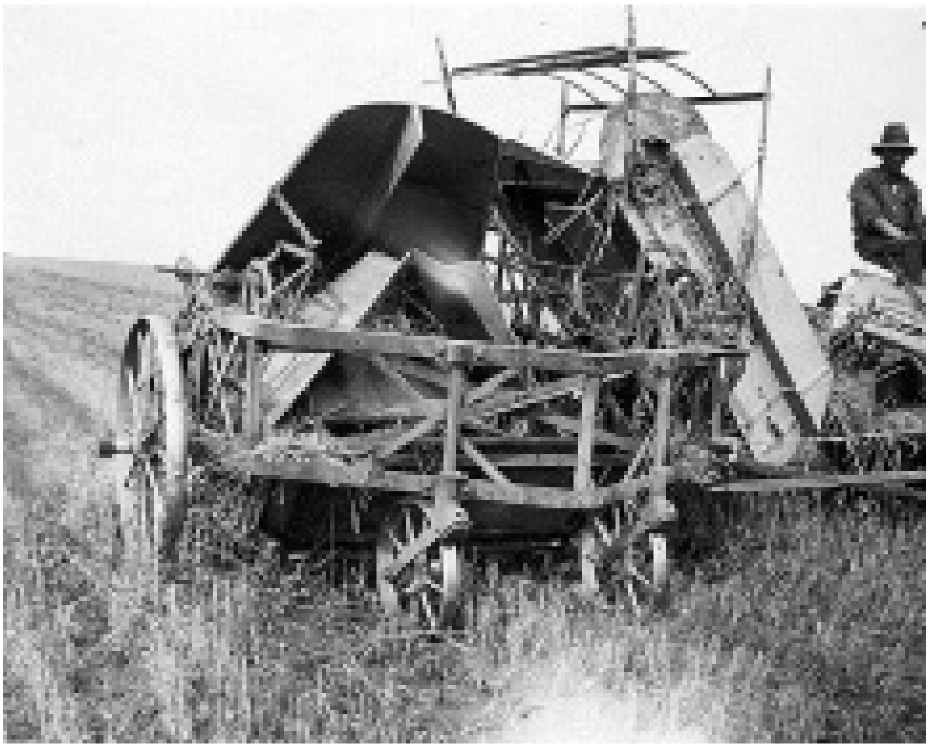

Figure 39: International Harvester Co. automatic stooker*, c.* 1926.

Most, if not all, automatic stookers formed a stook by collecting a number of sheaves and tying an additional band of twine around them, before depositing the completed stook onto the ground. It is acknowledged that this characteristic, together with the physical arrangement in which the sheaves are configured, could adversely affect airflow through the stook, and so restrict the rate and evenness of crop drying/ripening. These aspects would, therefore, require particular attention. However, given the significant manual labour requirement for stooking straw when harvested by the Conventional method, and the potential operational and economic advantages that automatic stooking could offer, it would seem highly advisable to explore the practicability of automatic stooking machines – albeit potential designs that are configured to suit UK harvesting conditions.

Self-loading mechanisms for hydraulically operated packaging cages (cradles)

The concept of mechanically elevating sheaves from the field onto a trailer or other transport vehicle is also far from new. The Chamberlain Crop Collector (Figure 40) was produced in the 1940s. It was a free-standing, petrol-powered elevator, designed to be towed alongside a trailer. Intended for collecting hay or straw from the swath, or sheaves from the stook, it comprised a ‘chain and (tined) slat’ elevator that lifted the crop and deposited it onto a canvas cross conveyor. This, in turn, dropped it onto the trailer, to be stacked manually. It is not known if this machine was a commercial success.

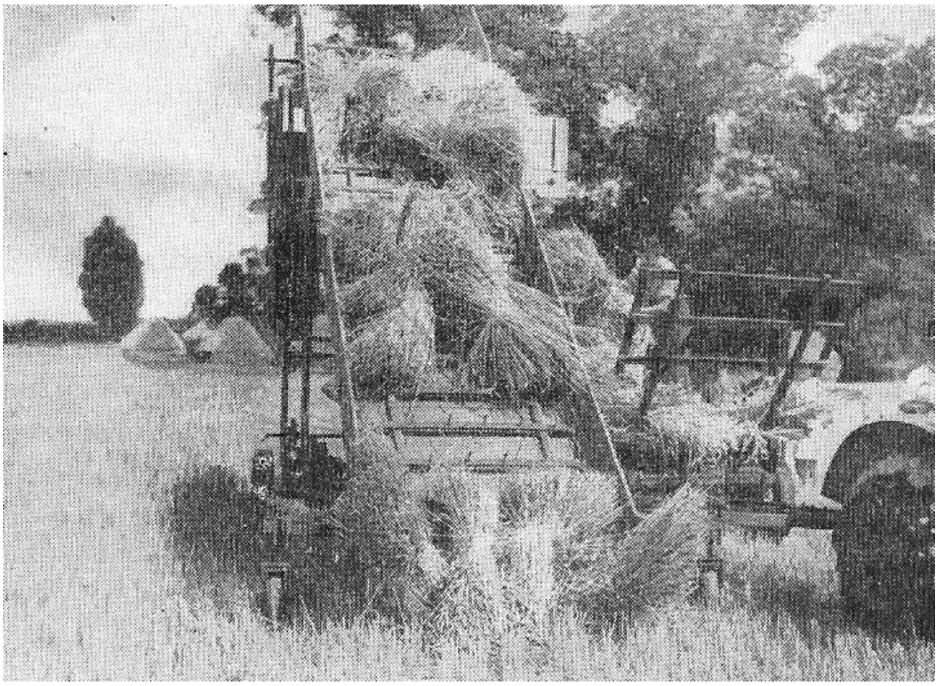

Figure 40: Chamberlain Crop Collector picking up sheaves of wheat from the stook, *c.* 1943.

Certain thatching straw growers have developed similar elevator-based machines for collecting sheaves from a swath and lifting them to a trailer-mounted platform. Here, they are loaded into a conventional hydraulically operated packaging cage by two workers. When the cage is full, the compressed package is manually tied and discharged back onto the field to await collection.

Such machines display considerable inventiveness and achieve a degree of labour saving. However, the need to overlap some of the sheaves when filling the cage (in order to create a stable package, *see* Section 3.1.6) makes it difficult to eliminate manual labour from the cage-filling process. This aspect is perhaps worthy of further investigation. Similarly, automatic tying of the packages would further reduce the labour requirement.

It is understood that growers who use such elevator-based machines currently remove the sheaves from the stooks and arrange them (transversely) in swaths, prior to pick-up by the elevator. Such an approach undoubtedly aids crop transfer and minimises the possibility of product damage. However, the formation of swaths is an additional (manual) activity prior to collection and, furthermore, when placed in windrows, the crop is (temporarily) at greater risk of weather damage than when in the stook. Nonetheless, the benefits offered by this technique warrant further investigation.

5.1.3 Crop processing

Irrespective of the product (LS or CWR), thatching straw harvested by the Conventional method is processed by static equipment. This operation is often partially or totally protected from the elements by some kind of shelter or building.

Issues concerning the significant labour requirement to feed crop material into the processing equipment and subsequently remove both the end product and any waste are well recognised (*see* Section 3.1.5). Similarly, the poor working environment in the vicinity of such machinery is also a recognised issue and is considered by many growers to require attention.

Consequently, opportunities for improvement in both the activity of crop processing and the associated machinery are deemed to include:

- Automated (conveyor) feeding of crop material to the threshing drum or comber, to reduce labour requirement and improve operator working environment.
    - Some growers have already made improvements in this area, but most concern the removal of waste materials. Many opportunities for further cost-effective improvements exist, but challenges remain.

- Dissemination of appropriate solutions for working area dust extraction, to improve operator working environment in the vicinity of crop processing equipment.
    - Wherever possible it is desirable to remove personnel from an unpleasant working environment, but this is not always practicable. Alternatively, suitable dust extraction systems may be both cost-effective and may lend themselves to on-farm construction and installation.
- Dissemination of basic recommendations for installation of guarding on straw processing machinery (to be developed in association with the Health and Safety Executive).
    - The majority of growers have already addressed machine safety by provision of appropriate guards, but sharing information regarding on-farm guarding solutions and/or alternative approaches to reduce or remove risk(s) could be beneficial.

5.1.4 Post-processing crop packaging

Some of the following suggestions have already been described. However, this highlights how development of a particular concept or improvement can provide benefits in more than one area of the (Conventional) crop harvesting process.

Possible opportunities to improve the operational efficiency and reliability of post-processing crop packaging equipment include:

- Dissemination of guidance regarding the maintenance and set-up of (original) knotter mechanisms fitted to straw trussers.
    - These mechanisms are old and often unreliable. Some growers have experience of their set-up and adjustment, and the scope for their refurbishment. Wider dissemination of this information would be beneficial.
- Replacement of (old/worn/unreliable) trusser knotter mechanisms with commercially available knotter units from conventional balers. Dissemination of suitable technical guidance and recommendations.
- Exploring scope for the development of self-loading mechanisms for crop packaging cages (cradles).
- Exploring scope for development of self-knotting mechanisms for hydraulically operated crop packaging cages (cradles).

5.2 Alternative harvesting method

As already mentioned, in many instances, proponents of Alternative harvesting and processing method have already exploited many of the opportunities available to improve the efficiency and cost-effectiveness of thatching straw harvesting and processing operations. They have selected and adapted, or even constructed, the bespoke equipment required, and their businesses have benefited accordingly.

However, there is still scope for further improvements in certain areas. These could potentially include:

- Removing the requirement for manual labour to prepare the swath for crop packaging (baling).
- Improving/enhancing product quality by more refined methods of (mechanical) swath preparation and subsequent crop packaging.

While the precise challenges faced by growers who use Alternative methods may differ from those who use Conventional methods, as in many aspects of agricultural mechanisation, there is considerable scope for cross-fertilisation and sharing of ideas. Frequently, a solution to one problem can be adapted and reutilised to address another. For this reason, if for no other, communication between the relatively small number of thatching straw growers in the UK should be encouraged at every opportunity.

6. Recommended next steps

This initial (Phase 1) investigation has highlighted the complexity of thatching straw harvesting and processing and identified mechanisation solutions that have the potential to improve the efficiency of harvesting and processing operations. If practicable and economically viable, these may, in turn, improve the long-term sustainability of thatching straw production in the UK.

Additionally, the performance of this and other associated studies in early 2023 has created a very favourable environment for further engagement and positive collaboration, with both growers and thatchers: this being noticeably different to the reticence demonstrated by some in the recent past. It is strongly recommended that this opportunity be exploited in the immediate term.

This initial research was always envisaged to be the first stage of a larger study. With this in mind, recommended next steps include:

- Undertake additional face-to-face engagement with significant growers in Devon and Somerset, who currently use Conventional methods to harvest and process large volumes of crop. (NB: This activity has now been completed.)
- Explore the feasibility of developing new machinery and/or adapting existing equipment to make thatching straw harvesting and processing more efficient. Recommended areas for initial focus are:
    - Mechanisation of crop handling relating to in-field ripening (Conventional).
    - Techniques and equipment for in-field packaging and handling of the crop from field to store (Conventional).
    - Crop handling relating to crop processing and subsequent packaging for onward sale (Conventional).
- Encourage the establishment of channels and/or opportunities for the exchange of mechanisation ‘hints and tips’ between growers.
- Explore ways to collaborate/partner with growers in the future development and proof-of-concept implementation of more refined and efficient harvesting machinery and associated mechanisation solutions.

- Develop and actively disseminate best practice guidance for growers regarding the selection, utilisation, maintenance and adaptation of harvesting and processing equipment. Specific objectives to include:
    - Maintain/improve/optimise thatching straw product quality.
    - Reduce labour input and production costs.
    - Integrate improved equipment and/or mechanisation solution(s) into the harvesting and processing methods currently used.
    - Obtain best performance from machinery, via appropriate set-up and pre-season maintenance.
    - Improve operator working environment and safety at work.

It is recommended that Phase 2 of this investigation considers these steps, alongside its broader objective to explore the feasibility of the potential mechanisation solutions identified by this work.

The potential pitfalls and opportunities that are likely to relate both to these and subsequent activities in this subject area are considered to be:

Pitfalls

- Failure to engage adequately with thatching straw growers and associated thatchers.
- Failure to appreciate the diversity of grower requirements and, more importantly, of the harvesting and processing methods used.

Opportunities

- Scope for engagement with growers of thatching straw (and potentially with associated thatchers) regarding a common cause.
- Encouraging the exchange and centrally organised dissemination of information regarding:
    - Opportunities for improvement of equipment and harvesting system performance and efficiency.
    - Maintenance/improvement of thatching straw product quality.
- To collaborate/partner in the future development and proof-of-concept implementation of more efficient harvesting machinery and associated mechanisation solutions.

7. Summary and conclusions

The overall aim of this investigation is to identify appropriate mechanisation solutions and equipment for harvesting of thatching straw, to make the process more efficient, safer, less labour-intensive and more financially viable. This (Phase 1) work focused on identifying machinery-related issues currently experienced by thatching straw growers, and also possible options for mechanisation improvements. Phase 2 is expected to investigate the practicability of these mechanisation solutions and explore options for implementing the most promising examples.

Harvesting and processing of thatching straw is a complex, multi-stage, weather-dependent process that involves numerous individual operations. Depending on the processing method used, the crop may be prepared as two alternative end products: LS or CWR.

Irrespective of the end product, thatching straw may be harvested and processed by two different generic approaches, defined by this investigation as the Conventional and the Alternative methods.

Crop harvested by the Conventional method is cut (with grain attached) when partly ripe; it is ripened in-field, and then is transported, stored and eventually processed using static equipment, to remove the grain – usually outside of the harvesting season. In the Alternative method, the crop is harvested at a more advanced stage of ripeness. The grain is removed from the standing crop, and the straw is then cut, processed and packaged, all as in-field operations at the time of harvest. In each method, a considerable variety of equipment and techniques are used.

At present, approximately 80 per cent of the UK crop is harvested and processed by the Conventional method, and this dominance is likely to continue. However, many aspects of the Conventional harvesting method are inefficient. Consequently, it offers considerable scope for efficiency improvements and overall cost reduction, by the implementation of appropriate mechanisation solutions. In many instances, individual growers have already made improvements, but a great deal more may still be done.

Although small in number, proponents of the Alternative method have implemented process changes, embraced mechanisation and improved operational efficiency. Some thatchers view the end products of the Alternative method with a degree of suspicion, whereas others regard them as perfectly acceptable. While the Alternative harvesting method is considerably more efficient than the Conventional approach, some scope for product quality refinements exists.

Processes that offer the greatest potential for improvement are primarily those that are labour-intensive or involve a poor working environment. They include:

- In-field crop handling – in relation to crop ripening/stooking (Conventional).
- In-field crop packaging – prior to transport to store (Conventional).
- Crop processing: crop material transfer to/from static equipment and overall labour requirement (Conventional).
- Crop processing – improving operator working environment (Conventional).
- In-field crop handling and packaging – to enhance product quality (Alternative).

Thatching straw production in the UK is a small, niche market: about 60 growers cultivate approximately 3,500 acres (1,400ha) of crop. A minority (40 per cent) of growers account for the majority (approximately 80 per cent) of this area, but the majority of producers grow relatively small areas (less than 60 acres/24ha). Consequently, suitable mechanisation solutions must be found for both larger and smaller growers.

This relatively small customer base currently uses a range of different approaches to harvest and process the crop, often using equipment of limited financial value. These factors combined mean that the development of new harvesting equipment is unlikely to be regarded as a commercially viable activity by most machinery manufacturers.

At present, thatching straw growers have little option other than to satisfy their harvesting and crop processing mechanisation requirements by the following means:

- Use of old (vintage) agricultural machinery, following established operating procedures.
- Adaptation of newer (commercial) agricultural machinery.
- Design, development and construction of their own bespoke equipment.

It is unrealistic to expect most growers to develop appropriate mechanisation solutions to these problems, either in isolation or entirely from their own resources. Rather, such solutions need to be developed, perhaps by a third party (or parties) such as Historic England or Historic Environment Scotland, working in conjunction with growers – particularly as commercial manufacturer involvement is unlikely to be forthcoming (at an economically viable cost).

Nonetheless, growers need to be prepared to invest (time and/or money) in appropriate mechanisation solutions, to improve the economic viability and sustainability of their operations. Perhaps if they play an active role in selecting, developing and refining such solutions, there may be a greater level of eventual take-up within the industry.

Potentially the most effective route by which improvements in crop harvesting and processing could be transferred to the end user (following machine development and proof-of-concept demonstration, ideally in conjunction with a grower consortium or an industry association) would be by provision of free-to-use design drawings. These would enable growers or their agents to construct or adapt appropriate machinery for their own use. Other independent bodies (CoSIRA) have used this approach in the past within this sector, with some success.

In addition to investigating the practicability of the mechanisation solutions and exploring options for implementing the most promising examples (in Phase 2), the following activities are recommended as complementary next steps:

- Host a ‘grower workshop’ event to engage with the industry, disseminate research findings to date and obtain feedback to help guide future activities.
- Develop and actively disseminate best practice technical guidance for growers, regarding selection, use and possible adaptation of harvesting and processing equipment. Specific objectives are to optimise/improve product quality, reduce labour and production costs, obtain best performance (via appropriate set-up and pre-season maintenance) and improve operator working environment and safety.
- Explore possible avenues by which to collaborate with growers in the future development and possible proof-of-concept implementation of more refined and efficient harvesting machinery. This could include the establishment and coordination of consortia to bid for government research and development funding in the agricultural sector.
- Encourage the establishment of channels and/or opportunities for the exchange of mechanisation ‘hints and tips’ between growers. However, the subject matter need not necessarily be limited to machinery-related topics.

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