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Front cover:
"A tractor-powered straw chopper showing the cross-wind conditions which can cause problems with spreading and incorporating chopped straw. (Photo: AFRC Engineering)

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Purchase prices of farm machines

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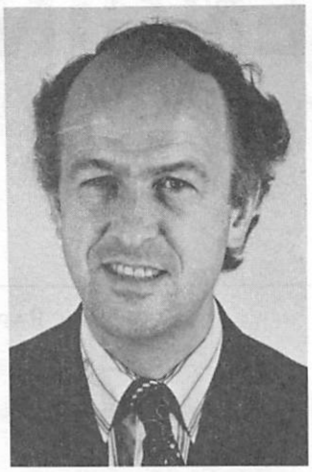

Brian Witney

Summary

THE selection of correctly matched machinery complements involves both technical and economic data. Direct comparability of product prices over the full range of machine sizes is seldom easy because individual manufacturers concentrate on different sections of the market and list prices are revised at different times of the year. For machinery management purposes, the unique price bargain is of secondary importance compared with a market analysis of inflation proof purchase price trends.

The purchase prices of farm machines are shown to be linearly related to their size descriptors, such as power rating for tractors and number and spacing of bodies/coulters/tines for ploughs, drills and cultivators, respectively. Approaching 90% of the price variation was explained by the purchase price regression equations for the majority of the machine types. In addition, an index-linking procedure is employed to update historical price data over a six to eight year period within ± 14% of the current prices over the full range of machine sizes.

1 Introduction

Investment in machinery plays a vital rôle in the profitability of the farm business. These investment decisions involve the expenditure of large sums of money and, as machinery purchase takes place relatively infrequently, experience is only gained over the longer term. In consequence, there is often undue emphasis placed on the immediate bargain without considering the market as a whole. Preceding the bargaining phase are, firstly, the strategic planning of the overall mechanisation policy and, secondly, the technical specification of the individual machines. Almost without exception, complements of farm machines have evolved gradually into workable combinations. Planning, on the other hand, requires a much broader awareness of the machinery market: not only is it necessary to match different sizes of machines to the appropriate tractor power level, but also to identify the cost of the various options. This involves a knowledge of the marginal price change for increased machine size or width within and between product ranges, as well as keeping abreast of price trends through inflation and technical improvements.

Rather than rely on random data, the purchase prices of particular categories of farm machines have been successfully related to size parameters, such as the rated engine power of tractors and the width of cultivators. This is not unexpected in a highly competitive market where the list prices are closely determined by the manufacturing costs for the design specification, plus a realistic profit margin. These empirical price trend equations are of limited practical use, however, because they become quickly dated by general price rises. In the present study, this restriction is overcome by the addition of a machinery price index to account for the effect of inflation. The ability to evaluate purchase prices accurately over a period of several years is important not just in machinery planning but also in relating historical depreciation and repair costs to current values.

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2 Previous work

The concept of proportionality of capital investment to machine size is by no means new. In a number of studies, the purchase prices of tractors have been linearly related to the rated engine power (Hunt 1963; MacHardy 1966; Witney and Eradat Oskoui 1982), whilst Cotterell and Audsley (1976) separately identified the extra cost of ballast for draught work in their analysis of cultivation costs:

$$PP_t = a_t + b_t P_{pto} + c_t B \quad . . . 1$$

where: a_t, b_t, c_t = price coefficients;

P_{pto} = tractor power take-off power, kW;

PP_t = tractor purchase price, £;

B = tractor ballast, t.

The values of the price coefficients vary from one year to another and from one country to another, but the general form of the equation remains valid.

Rather more complex functions of width and speed were developed to predict the purchase prices of mouldboard ploughs (Zoz 1974). This approach was adapted for chisel ploughs (Cottrell and Audsley 1976), whilst the prices of rotary diggers were influenced by a cubic term of power input together with a linear term of machine width. The justification for relating draught cultivator prices to speed is not immediately apparent because implement design is dictated by the maximum impact loading, whether or not the operating speed ever reaches the upper limit of its design range. Indeed, the reason for the inclusion of a speed related price coefficient appears to have been conditioned partly by the application of the price functions in an analysis of the effect of width and speed on 'least cost' tillage. Perhaps, more realistically, the effect of greater speed should be reflected in higher repair costs (Rotz, 1985) but the final effect is similar because repair costs which are usually determined as an increasing proportion of the initial purchase price with machine age are an essential element of machinery operating costs. Subsequently, a satisfactory correlation of mouldboard plough prices was obtained as a linear function of number of furrows (Witney and Eradat Oskoui 1982).

Although the link between greater component strength and hence price is appropriate for increasing sizes of power driven cultivators, it is questionable whether it is necessary to adopt a cubic function of power consumption when tractor prices are assumed dependent on a linear function of power generation. A greater problem, however, is acquiring precise power requirements for rotary cultivators.

3 Assessment of tractor and machinery prices

Data was collected on the list prices of a wide range of farm machines, including two-wheel drive, front-wheel assist, four-wheel drive and crawler tractors (Anon 1977a & 1983b), mounted/semi-mounted conventional and reversible ploughs equipped with either fixed or auto-reset legs (Anon 1980 & 1983a), mounted/trailed grain-only and combine drills (Anon 1976, 1978 & 1984b), and power driven cultivators (Anon 1977b & 1984a). Initial price equations for these machine types were developed using regression analysis (Elbanna 1986).

3.1 Tractor purchase prices

The purchase prices of two-wheel drive, front-wheel assist, four-wheel drive and crawler tractors with a similar technical specification were found to be linear functions of the maximum power take-off power:

$$PP_t = a_t + b_t P_{pto} \qquad \ldots 2$$

where: a_t, b_t = price coefficients dependent on tractor type;

P_{pto} = maximum power take-off power, kW;

PP_t = tractor purchase price, £.

The values of the various price coefficients, their standard errors and percentages of the variation explained by the regression equation for each tractor type are given for both 1977 and 1983 data (table 1). About 88% of the price variations are explained by this simple form of equation, as indicated for two-wheel drive tractors in figure 1. There is also a general increase in the value of both the coefficients between 1977 and 1983, but the percentage change in values is by no means consistent. As the tractor type increases in design complexity (or decreases in market share), so the power related price coefficient, b_t, becomes more significant relative to the independent price coefficient, a_t (fig 2). Indeed, the values of the independent price coefficient, a_t, were not always significant because there were several standard errors which were an order larger than the parameters. This suggests that the price relation maybe curvilinear but the additional complexity of a non-linear equation did not appear to be justified, apart from securing cosmetic improvements outwith the relevant market sector.

Table 1 Values of tractor price coefficients, their standard errors and percentages of the variation explained by the regression equations for September 1983 and July 1977.

Tractor	*Price coefficients [SE]* a_t	b_t	*Expl %*	*Degree of freedom*
September 1983				
2-wheel drive	2000 [331]	191 [5.36]	88	168
Front-wheel assist	47.9 [755]	264 [9.63]	89	144
4-wheel drive	-315 [2710]	306 [16.7]	94	24
Crawler	-9360 [3270]	449 [42.3]	90	16
July 1977				
2-wheel drive	-118 [295]	134 [4.85]	90	87
Front-wheel assist	-755 [501]	176 [4.80]	96	58
Crawler	-9300 [3480]	347 [53.2]	74	16

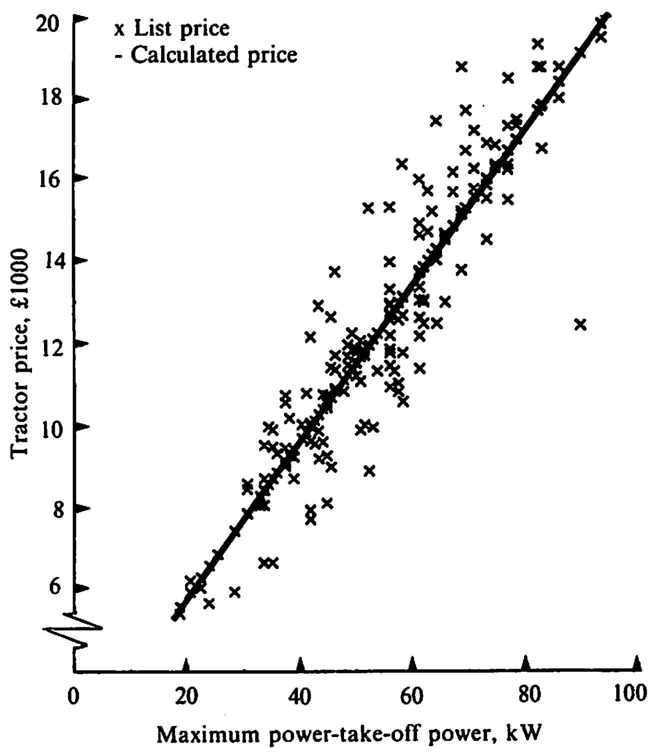


Fig 1 Variation of the purchase price of two-wheel drive tractors with maximum power take-off power (1983 data)

3.2 Machinery purchase prices

The list prices of various ploughs, drills and cultivators were linearly related to their major components, such as the number and spacing of bodies/coulters/tines.

3.2.1 Plough prices

The major size descriptors for ploughs, namely the main

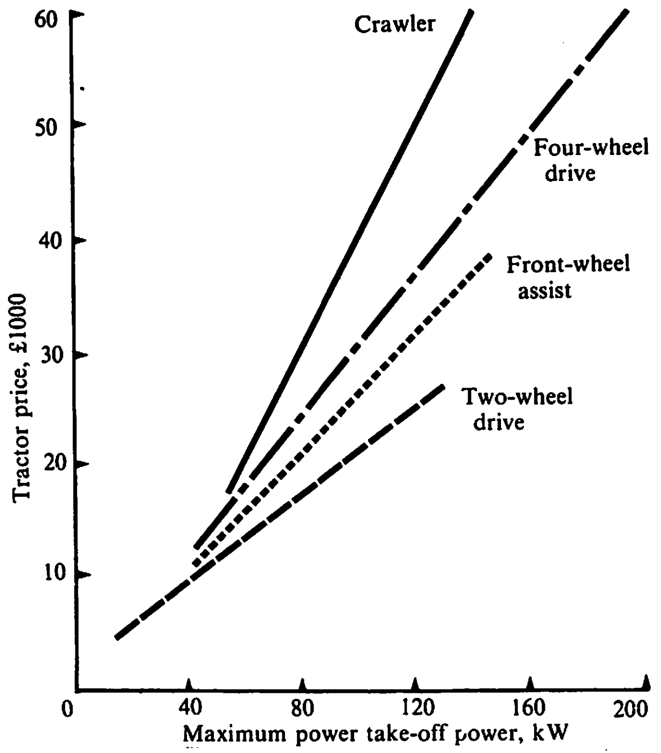


Fig 2 Variation of the purchase prices of different types of tractor with maximum power take-off power (1983 data)

frame per furrow and the number of plough bodies, were included in a linear price equation of the form:

$$PP_p = a_p + b_p w_f + c_p N_b \qquad \ldots 3$$

where: a_p, b_p, c_p = price coefficents dependent on plough type;

N_b = number of plough bodies;

PP_p = plough purchase price, £;

w_f = width of furrow, mm.

The analysis included mounted/semi mounted conventional and reversible ploughs with either fixed or auto-reset legs. The regression coefficients, their standard errors and percentages of the variation explained by the regression equations for various plough types are given for both 1980 and 1983 data (table 2). The greatest volume of price data was obtained for mounted, conventional and reversible ploughs with fixed legs for which between 74% and 88% of the variation was explained by the regression analysis.

There was also a consistent trend in the values of the price coefficients for those plough types.

A change in frame design from mounted to semi-mounted and from conventional to reversible specification jointly affected the independent price coefficient, a_p, and the furrow width related price coefficient, b_p; whilst the addition of automatic resetting of the plough leg after hitting an obstruction infleunced the plough body related price coefficient, c_p. the reversible plough having twice as many bodies as the same width of conventional plough. The correlation between the predicted and the list prices for various conventional and reversible ploughs are illustrated in figures 3 & 4.

3.2.2 Drill prices

The purchase prices of mounted/trailed versions of conventional and combine drills, trailed cultivator drills, and trailed direct drills were investigated. The relevant size descriptors in a linear price equation for grain drills were found to be the machine width per coulter and the number of coulters:

$$PP_d = a_d + b_d w_c + c_d N_c \qquad \ldots 4$$

where: $a_d, b_d c_d$ = price coefficients dependent on drill type;

N_c = number of coulters;

PP_d = drill purchase price, £;

w_c = coulter spacing, mm.

Table 2 Values of plough price coefficients, their standard errors and percentages of the variation explained by the regression equations for August 1983 and July 1980.

Plough	*Price coefficients [SE]* a_p	b_p	c_p	Expl %	Degree of freedom
August 1983					
Conventional:					
mounted, fixed leg	-249 [427]	0.372 [1.31]	493 [27.9]	89	48
mounted, auto-reset	5330 [1940]	-15.6 [5.79]	623 [74.8]	91	9
semi-mounted, fixed leg	4830 [2130]	-18.1 [6.03]	1180 [92.9]	91	17
semi-mounted, auto-reset	-20400 [3050]	57.7 [9.20]	737 [157]	96	7
Reversible:					
mounted, fixed leg	-1760 [587]	5.75 [1.73]	937 [47.2]	84	92
mounted, auto-reset	-1840 [4250]	8.52 [11.9]	875 [142]	79	12
semi-mounted, fixed leg	106000 [31300]	-294 [89.9]	755 [163]	78	9
semi-mounted, auto-reset	-127000 [57500]	363 [16.6]	1526 [336]	98	3
July 1980					
Conventional, mounted, fixed leg	-745 [373]	2.06 [1.09]	373 [26.6]	74	75
Reversible, mounted, fixed leg	-476 [947]	15.2 [2.73]	652 [51.2]	79	65

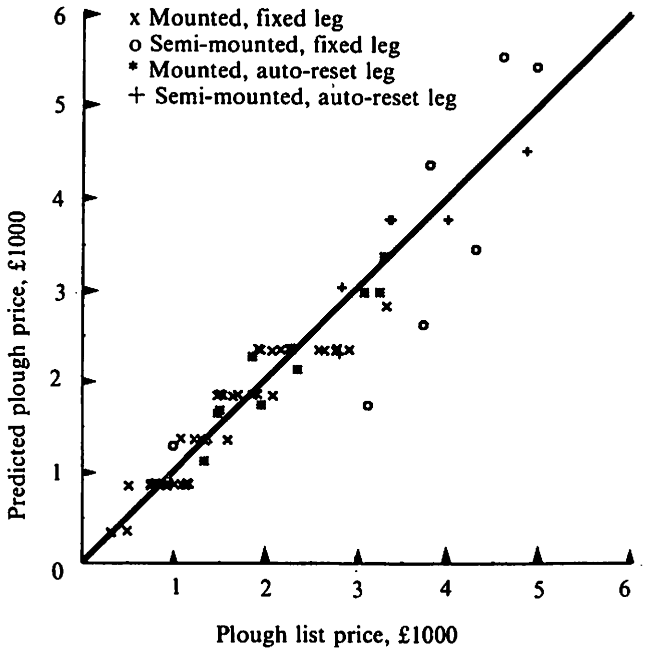


Fig 3 Comparison between the prices listed for various types of conventional ploughs and those using a price trend equation (1983 data).

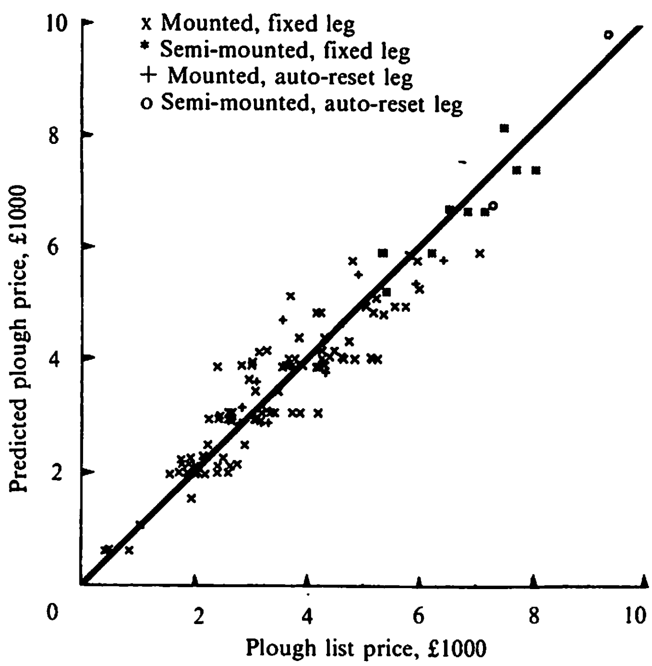


Fig 4 Comparison between the prices listed for various types of reversible ploughs and those using a price trend equation (1983 data).

The regression coefficients, their standard errors and percentages of the variation explained by the regression equations are given for various drill types using 1976, 1978 and 1984 price data (table 3). Apart from the limited data for mounted combine drills (including direct drills and cultivator drills), between 72% and 93% of the price variation was explained by the regression. Mounted and trailed conventional drills, together with trailed combine drills represented the greatest proportion of the price data. The frame design for mounted or trailed versions, the provision of a fertiliser hopper, in addition to one for grain, and the extra complexity or strength of coulters for direct drilling compared with drilling into a prepared seedbed, all influenced the values of the price coefficients. Nonetheless, a good correlation was obtained between the predicted prices and the list prices of a range of drills (fig 5).

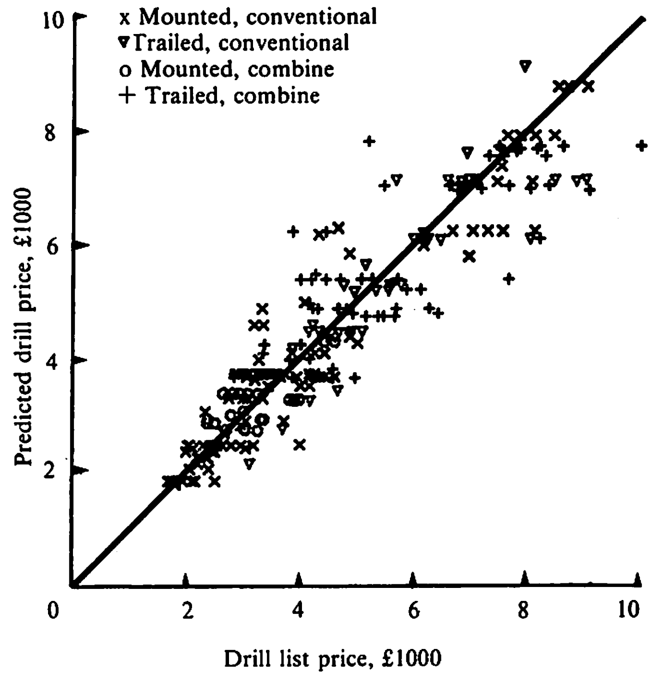


Fig 5 Comparison between the prices listed for various types of grain drills and those using a price trend equation (1984 data).

3.2.3 Power driven cultivator prices

A slightly different form of price equation was used for power driven rotary cultivators in that machine width was taken as a cost parameter instead of spacing between blades or tines. This change was necessary because the blade/tine spacing on a rotary cultivator was related not only to a horizontal dimension but also to an angular position on the rotor. The linear price equation included machine width and number of blades or tines:

$$PP_c = a_c + b_c w_m + c_c N_t \quad \ldots 5$$

where: a_c, b_c, c_c = price coefficents dependent on rotary cultivator type;

N_t = number of blades/tines;

PP_c = purchase price of power driven rotary cultivator, £;

w_m = machine width, m.

A further complication arose with the price equation for power harrows. The number of tines became a misleading parameter because of the different types of oscillating and orbital drive mechanisms incorporated in power harrow design and was, therefore, excluded from the price equation.

The regression coefficients, their standard errors and the percentages of the variation explained by the

Table 3 Values of drill price coefficients, their standard errors and percentages of the variation explained by the regression equations for August 1984, July 1976 and March 1978.

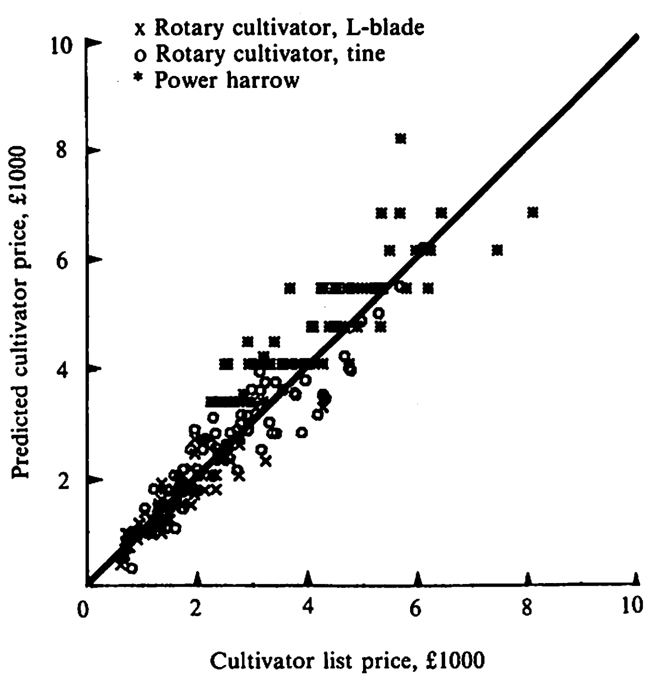
	Price coefficients [SE]				
Drill	a_d	b_d	c_d	*Expl %*	*Degree of freedom*
August 1984					
Conventional, mounted	-5780 [497]	35.6 [3.49]	156 [5.0]	89	121
Conventional, trailed	-3320 [865]	23.5 [5.08]	233 [9.2]	93	56
Combine, mounted	-7820 [2380]	68.3 [15.10]	105 [46.4]	63	15
Combine, trailed	-4780 [851]	27.6 [4.27]	275 [14.2]	86	64
Combine, trailed (inc direct and cultivator types)	-9280 [1030]	48.7 [5.73]	346 [14.9]	86	89
July 1976					
Conventional, mounted	-3080 [577]	15.9 [2.92]	88.3 [8.6]	72	40
March 1978					
Conventional, trailed	-1900 [1460]	8.65 [7.23]	142 [18.3]	91	10

Table 4 Values of cultivator (power driven) price coefficients, their standard errors and percentages of the variation explained by the regression equations for June 1984 and November 1977.

	Price coefficients [SE]				
Cultivator	a_c	b_c	c_c	*Expl %*	*Degree of freedom*
June 1984					
Rotary, L-blade	-396 [141]	354 [150]	30.8 [4.1]	86	73
Rotary, tine	-823 [194]	1340 [104]	5.5 [2.3]	84	73
Harrow	-2550 [347]	1970 [86.6]	- -	88	72
November 1977					
Rotary, tine	-777 [239]	806 [183]	13.5 [6.2]	77	72
Harrow	-1330 [324]	1290 [102]	- -	88	21

regression equations are given for both power driven rotary cultivators and for power harrows using 1977 and 1984 prices (table 4). The predicted prices are compared with the list prices of various types of power driven cultivator in figure 6.

Fig 6 Comparison between the prices listed for various types of power driven cultivator and those using a price trend equation (1984 data).



4 Machinery price indices

Purchase prices for any one year are severely limited in their usefulness, to the extent that reference to a current price guide is easier and quicker than applying the purchase price equations. Fortunately, the availability of official price indices simplify the updating of prices on a monthly or annual basis (MAFF). The price indices for tractors and machinery (including ploughs, drills and cultivators) are listed in table 5 for the past ten years. Using the appropriate index values, it is possible to convert historical prices to current values and vice versa. For example, updating prices from 1981 to 1984 requires the following conversion:

$$PP_{84} = PP_{84}.I_{84}\ I_{81} \quad \ldots 6$$

where: I_{81}, I_{84} = price index for 1981 or 1984;
PP_{81}, PP_{84} = purchase price for 1981 or 1984, £.

This index-linking procedure was applied to relate the tractor and machinery prices equations for different years.

The purchase prices of various power ratings of two-wheel drive, front-wheel assist and crawler tractors were obtained from the price trend equation (eqn 1) for July, 1977 and for September, 1983, the earlier prices being updated by means of equation 6 (table 6). The percentage differences between the two sets of prices were quite modest for 50 kW to 100 kW two-wheel drive tractors (1

Table 5 Ten year price indices for various categories of farm equipment

Year	Tractors	All agricultural machinery	Soil preparation and cultivation machinery
	Annual price indices; 1980 = 100		
76	57.1	54.9	58.7
77	71.3	66.2	70.3
78	80.6	77.1	80.5
79	89.4	88.3	88.5
80	100.0	100.0	100.0
81	108.5	104.9	101.8
82	114.8	111.9	106.3
83	124.9	114.2	110.3
84	134.1	119.1	115.3
85	143.8	126.5	121.0

Table 6 Purchase prices of various power ratings of two-wheel drive, front-wheel assist and crawler tractors using the September 1983 and the July 1977 price trend equations, together with the 1977 price index-linked to 1983.

Power rating, kW	Purchase prices, £ Sept '83	July '77	Index-linked '77 to '83	Difference %
2-wheel drive				
50	11 600	6 570	11 500	0.8
75	16 400	9 920	17 400	-6.1
100	21 200	13 270	23 300	-9.9
Front-wheel assist				
50	13 200	8 040	14 100	-6.8
75	19 800	12 400	21 800	-10.1
100	26 400	16 800	29 500	-11.7
125	33 000	21 200	37 200	-12.7
150	39 600	25 600	45 000	-13.6
Crawler				
50	13 100	8 060	14 200	-8.4
75	24 300	16 700	29 300	-20.6
100	35 500	25 400	44 600	-25.6
125	46 700	34 100	59 900	-28.3
150	57 900	42 800	75 200	-29.9

% to -10%) and for 50 kW to 150 kW front-wheel assist tractors (-7% to -14%) but poorer price projections were obtained for 50 kW to 150 kW crawlers (-8% to -30%). The index-linked price predictions for the two-wheel drive and the front-wheel assist tractors were satisfactory over a six year timespan, whereas the real reduction in crawler prices possibly reflects a change in marketing policy to increase the competitiveness of crawlers which have been traditionally more expensive than their two-wheel drive counterparts.

Table 7 Purchase prices of mounted conventional and reversible ploughs with a furrow width of 350mm using the August 1983 and the August 1980 price trend equations, together with the 1980 price index-linked to 1983.

No of furrows	Purchase prices, £ Aug '83	Aug '80	Index-linked '80 to '83	Difference, %
Conventional				
2	867	683	729	15.9
3	1 360	1 070	1 170	15.9
4	1 850	1 460	1 560	16.0
5	2 350	1 850	1 970	15.9
6	2 840	2 240	2 390	16.0
Reversible				
2	2 130	1 870	2 000	6.0
3	3 060	2 530	2 700	12.0
4	4 000	3 180	3 390	15.2
5	4 940	3 830	4 090	17.2

Similar price trend comparisons were completed for conventional and reversible ploughs, mounted and trailed grain drills, power driven rotary tined cultivators and power harrows (tables 7 to 9). For the common sizes of 3 -5 furrow mounted ploughs, the August, 1980 prices (updated to August 1983) were consistently about 16% lower than the August, 1983 prices for conventional ploughs and from 6% to 17% lower for reversible ploughs (table 7). For 3 m to 6 m wide grain drills with close coulter spacing, however, the October, 1976 prices (updated to August 1984) ranged from 11% lower to 1% higher than the August 1984 prices for mounted drills, whilst the March 1978 prices (index-linked to August 1984) ranged from 13% to 7% lower than the August 1984 prices for trailed drills (table 8). A good price comparison was obtained for power driven cultivators and power harrows between the November 1977 prices (updated to June 1984) and the June 1984 prices, the price differences ranging from 8% to -3% for 2m to 5 m rotary cultivators and from -12% to 9% for 4 m to 10 m power harrows (table 9). The consistent price increases for ploughs in contrast to the close price predictions for mass-produced tractors, grain drills and power driven cultivators would suggest that some improvement in the equipment specification was superimposed on the general price increases due to inflation.

5 Conclusions

The comparison of the marginal price changes for different size combinations of farm machines is facilitated by the availability of inflation proof, purchase price trends for a range of tractors and equipment.

The purchase prices of farm machines are linearly related to their size descriptors, such as power rating for tractors, and the number and spacing of bodies/coulters/tines for ploughs, drills and cultivators. Approaching 90% of the price variation was explained by the regression equations for the majority of the machine types.

Table 8 Purchase prices of mounted and trailed conventional grain drills with a 0.100 m coulter spacing using the August 1984 and the October 1976 or March 1978 price trend equation, together with the appropriate price index-linked to 1984.

Machine width, m	Purchase prices, £				
	Aug '84	*Oct '78*	*Mar '78*	*Index-linked price*	*Difference, %*
Mounted					
3.0	2470	1160	-	2210	10.6
4.0	4040	2040	-	3890	3.7
4.5	4820	2490	-	4730	1.9
6.0	7170	3810	-	7250	-1.1
Trailed					
3.0	6020	-	3330	5230	13.1
4.0	8340	-	4650	7530	9.7
4.5	9510	-	5360	8680	8.7
6.0	13000	-	7490	12140	6.6

Table 9 Purchase prices of power driven, rotary-tined cultivators and power harrows using the June 1984 and the November 1977 price trend equations, together with the 1977 price index-linked to 1984.

Machine width, m	No of tines	Purchase prices, £			
		June '84	*Nov '77*	*Index-linked '77 to '84*	*Difference, %*
Rotary Cultivator					
2	26	1990	1190	1840	7.9
3	39	3400	2170	3350	1.4
4	52	4810	3150	4780	-1.4
5	65	6210	4130	6390	-2.8
Power harrow					
4	-	5320	3840	5940	-11.6
6	-	9260	6430	9940	-7.3
8	-	13200	9010	13900	-5.6
10	-	19700	11600	17900	8.9

Historical purchase prices can be updated by means of an index-linking procedure. With the exception of crawler tractors whose real price has decreased and of ploughs whose real price has increased, the purchase prices of two-wheel drive tractors, front-wheel assist tractors, grain drills and power driven cultivators, index-linked over periods of from six to eight years, were within ± 14% of the current prices.

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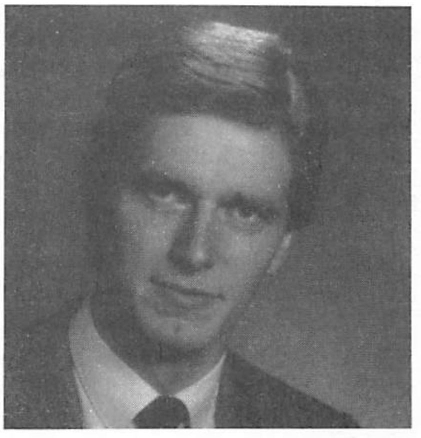
Developments in combine harvester design

H Garbers

Summary

OVER the years, the development of the combine harvester has been aimed at functional improvement of a known system of components in order to increase the general specific performance of the combine, particularly under difficult harvest conditions. In the early 1980s, an increase in combine capacity was sought beyond the capabilities of walker combines and this led to the development of non-conventional separation systems. However, these alternative systems are more complex in construction and have increased power requirements resulting in a higher capital cost; in addition some operators criticise the greater comminution of the straw. Since combines with alternative separation systems are only offered within the high capacity class, their market share in Europe has been limited to about 13% of this class. Therefore, developments will still include detail improvements to walker combine harvesters as such machines will retain the largest share of the market in the foreseeable future.



Introduction

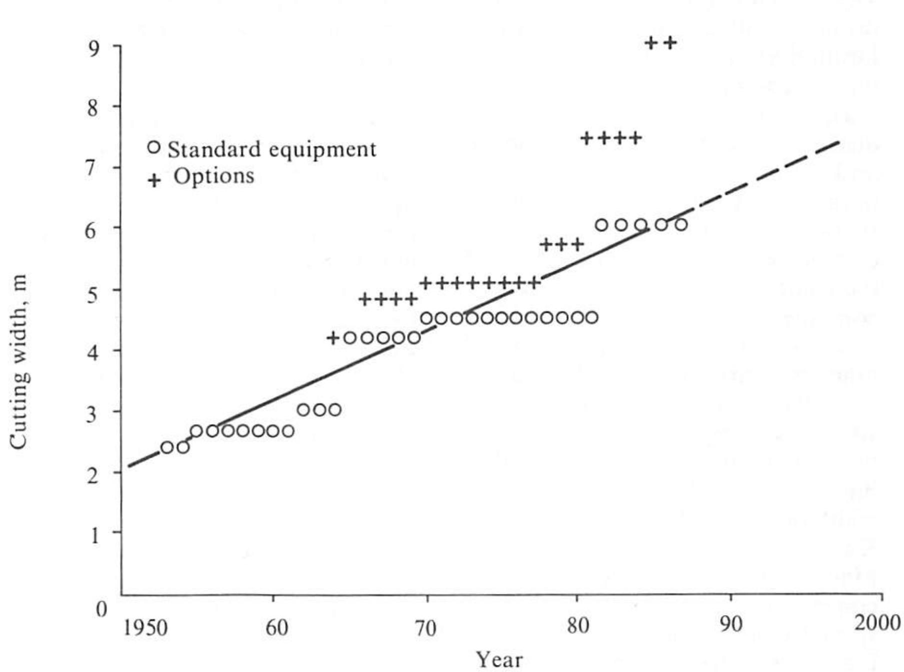
This paper details the developments of the different major components of a combine harvester and it also relates some field test data to these developments. Finally, objectives and trends in combine engineering are discussed.

Header

Starting at the header, upon which the performance of the combine largely depends, these are available in cutting widths from 2.5 to 9 m.

Figure 1 shows the wider end of the header sizes of the Claas combine range since 1950. There is a difference between the standard and optional header widths as the former show a linear increase over the years, while the optional header widths increase progressively. This is due to the demands of the export market. As the mounting geometry of headers onto the combine is the same throughout a range of header widths, the farmer can choose the width suitable for his demands, so that he can utilise the combine's capacity. The advantage of a smaller header is its ability to follow contours on rough fields and on sidehill operations. However, the combine output has to be maintained by use of a higher ground speed, resulting in vibration of the combine, and forward speed can be limited by the knife cutting speed. The smaller header option also requires additonal turning time. Combines working on a sidehill operation have a tendency to lean towards the lower side due to the change of the centre of gravity. The lower tyre will sink deeper resulting in a sloping height of cut over the width of the header and the possibility of the lower end of the knife fouling the ground. A solution to this problem occurs in several US patents and is offered commercially in that country. One is to mount the header centrally on a pivot located on the intake conveyor. A swinging

Fig 1 Cutting widths of largest Claas combines



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motion of ±3° is possible by sensing the ground contour.

The capacity of the header has been increased by use of a greater diameter and a larger pitch of the auger flighting. Retracting fingers throughout the width of the auger ensure trouble free continuous crop intake. Although other systems of crop cutting have been tried, they have not supplanted the reciprocating knife which remains the proven mechanism for actual field operation. A detail improvement is the use of oil bath knife drives which makes it possible to increase the knife oscillations to more than 550 cycles per minute. Double finger mounting and the use of self-sharpening knives has decreased downtime and wear of the cutterbar and knife. A double knife arrangement is used for harvesting rice, to ensure trouble free operation without blocking the cutterbar. To overcome blockages of the combine intake components, modern machines are equipped with an intake reversing system, driven either by an electric or hydraulic motor or by reversing gearbox. The reel is adjustable vertically and horizontally, the reel speed being adjustable mechanically by a variable drive. The hydrostatic reel drive, common in the USA, is little seen on European models. The whole header is hooked up to the combine intake conveyor by a quick attach system which includes drive shaft, electrical and hydraulic connections.

Threshing components

The wellknown tangential threshing drum is still dominant in Europe. Drum diameter has no real influence on the combine performance, most manufacturers selecting drum diameter from their own knowledge and experience (diameters are normally between 450 and 610 mm). It is the width of the threshing cylinder which defines the capacity of the combine. There are four sizes of combine currently on the market which are related to drum width and number of straw walkers, the number of walkers increasing from three to six with corresponding drum widths between 0.8 and 1.6 m. Drum width is limited to about 1.6 m as the total width of the combine is restricted by European traffic laws to 3 m. Manufacturers offer very similar concave shapes for cereals whereas special concave shapes are supplied for other crops like rice, maize or beans. Modern tangential threshing components work very well with relatively low threshing losses and kernel damage.

Straw walkers

The capacity of the straw walkers depends on the walker area. For the same reason as the drum, walker width is limited to about 1.6 m. An increase in the walker length only improves the separation capacity marginally because about 70% of the straw-grain separation takes place within the first third of the walker area. To optimise the walker capacity, most manufacturers are using alternative mechanisms to treat the straw layer. Claas uses the intensive separation system shown in fig 2 to break up the straw layer in the direction of its movement, while John Deere uses the cross-shaker system which distorts the straw layer in a sideways direction. Sperry New Holland treats the straw layer with a unique rotary separator before it reaches the walkers. Fiatagri is the only manufacturer who adjusts the speed and slope of the straw walkers for the actual harvesting conditions. Otherwise no real developments have taken place with the straw walkers during recent years.

Non-conventional separation systems

Alternative separation systems have been developed to meet requirements for higher combine throughput capacities outwith the limitations of current straw walkers. There is a market demand for combine harvesters with high crop throughputs to maintain good rates of ground cover in high yielding crops to reduce the time in the field so that harvesting is carried out under optimum conditions to minimise drying costs and crop weather damage. Manufacturers in the USA introduced walkerless combines in the early 70s. In the 80s the Europeans followed with other alternative separation combines. Generally we can distinguish between two systems:

(i) a complete axial flow system, where threshing and separation is carried out with the same rotor unit,

(ii) a split system, where the threshing is carried out with a tangential flow drum and the separation is done with either tangential or axial flow cylinders.

The crop flow in the complete axial flow systems is either axial to the direction of crop intake (New Holland TR and Case-IH Axial Flow) as shown in fig 3 or tangential (Allis Chalmers R-series and Fiat-agri) as shown in fig 4. The axial crop flow intake requires a sophisticated transition between the intake conveyor and the threshing drum. Manufacturers use either a propeller type component on the intake end of the drum or a set of augers to guide the crop flow into the drum. The tangential crop flow has no such intake problem but this system requires a wide machine. The axial rotors are completely surrounded by a concave, which have various shapes offered by the different manufactures. The crop flows through the system in a screw type manner, which produces a long pathway for the grain to be rubbed out of the heads. In the threshing part of the rotor there is a thicker layer of straw than is found in the conventional tangential flow drum where grain separation is mainly due to centrifugal forces. The straw layer on the concave in the separation part of the axial flow rotor is thinner than the layer found on conventional straw walkers but the straw is not teased so much.

In the split system, the straw walkers are replaced by an axial flow separation component. The advantage of this system is that separate adjustment is possible of the threshing and separation units. These split systems include the Claas Cylinder System and the New Holland Twin Flow System, both European developments. The straw walkers are replaced by the Claas CS-system with eight cylinder and concave arrangements as shown in fig 5, which can be adjusted in speed and concave clearance. This produces a thin even straw layer which is teased and turned repeatedly by changes in direction and speed. Having only replaced the straw walkers, none of the other components are changed so that optimum in shoe performance can be maintained. The straw walkers are replaced by New Holland with a second rotary separator and a transverse separation cylinder which produce a tangential-axial crop flow. The second beater and the tangential-axial flow arrangement generate several reversings of the straw layer and tease it well.

Fig 2 Claas intensive walker separation system

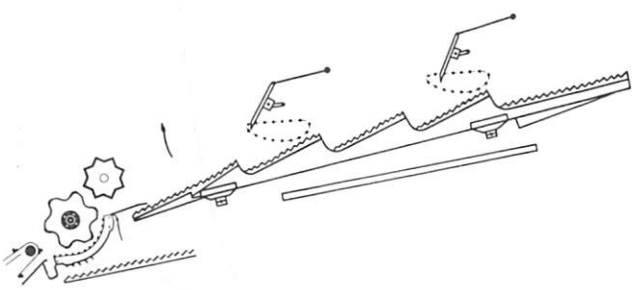


Fig 3 Axial flow systems

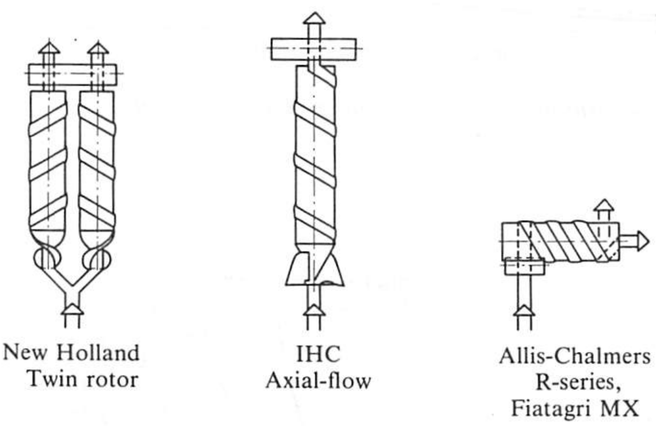


Fig 4 Walkerless systems with conventional drums and separation

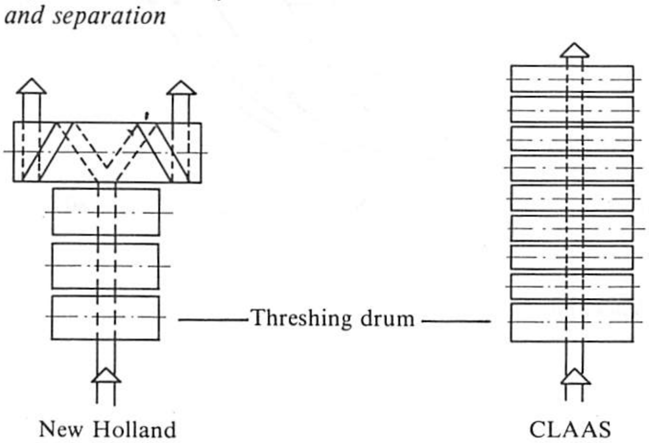
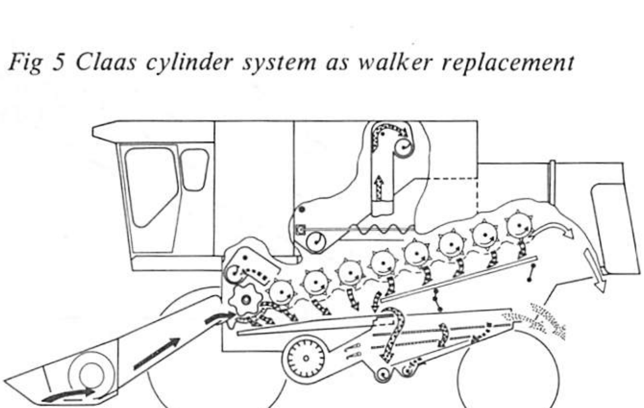


Fig 5 Claas cylinder system as walker replacement



All the alternative systems require forced movement of the straw between the cylinders and the concaves. This results in higher power requirements for these units and in more break-up of the straw. However, this forced movement ensures better hillside operations as lateral movement of the straw is restricted and it also provides a more even performance from the unit in changing crop conditions. This can be verified by the following performance assessments. The grain loss curve in fig 6 for the standard walker combines has a flat, almost linear slope at low feed rates and a progressively steeper slope at increasing feed rates. The transition between these two curves is rather abrupt which makes it difficult for the operator to harvest at the highest possible feed rate with low grain losses, especially under quickly changing crop conditions. However, the grain loss curve of the CS-system has a lower gradient at higher feed rates resulting in a less noticeable transition from the lower feed rates. Here the operator can work at a very high threshing capacity, even in changing crop conditions as grain losses will only marginally increase when an overloading of the unit occurs.

Diurnal crop conditions change especially with respect to moisture content. The following two graphs show the grain loss and time of day relationship of a standard walker combine and a CS unit. From fig 7, it can be seen that a walker machine having grain losses of 0.5% at a given feed rate in the early afternoon, will have increased losses of up to and over 1.0% by 7 pm. A comparable CS combine, as shown in fig 8, will not reach the 1% loss rate in the same field until 9 pm. These results generally indicate the better performance of the CS combine both under normal and more extreme conditions.

Cleaning components

With the more intense working of threshing and separation components, the proportion of short straw and chaff discharged onto the cleaning area has increased. This requires an improved performance from the component. Not only is sieve area an important measure of the cleaning capacity of a combine, but the right setting of the shoe frequency, the fan speed and the air blast direction also optimises the

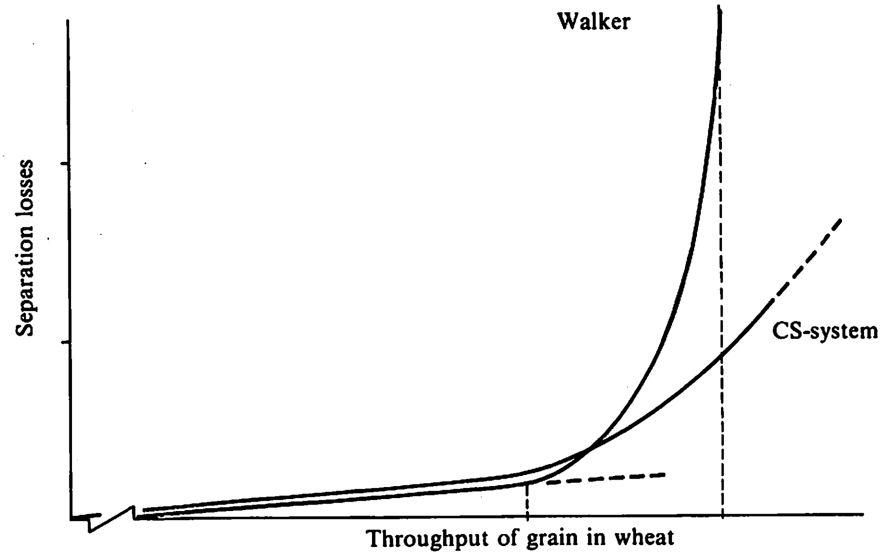


Fig 6 Comparison of separation losses from walker and CS combines

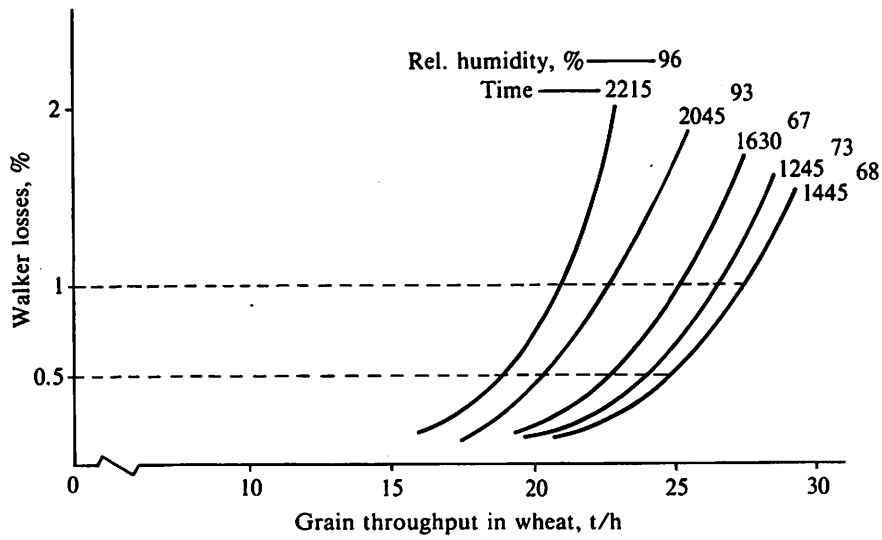


Fig 7 Walker losses depending on time of day

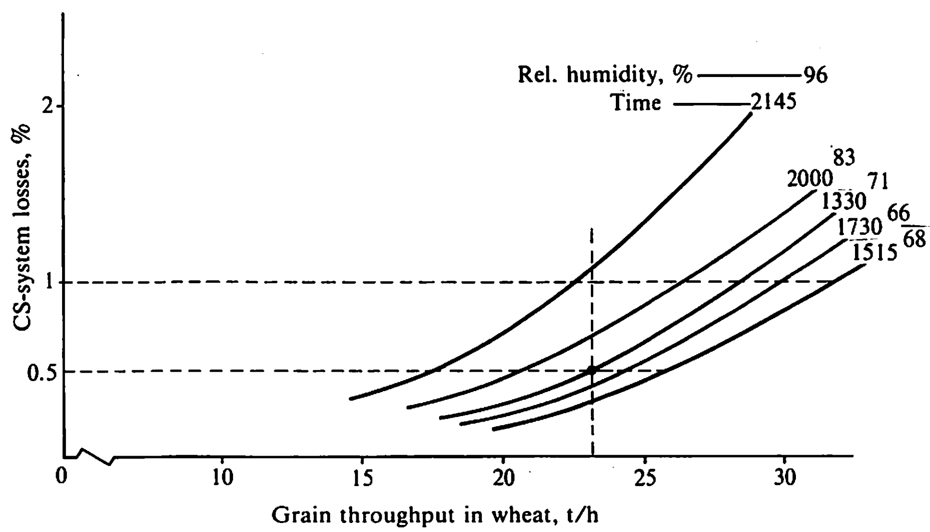


Fig 8 CS-system losses depending on time of day

cleaning capacity. The use of wide sieves make it necessary to fit a side-by-side fan arrangement to ensure even air distribution throughout the sievebox. The cleaning capacity has been increased by a further 25% with the use of a ventilated double step grain pan as shown in fig 9. In this way, the lighter chaff does not come into contact with the sieves, as it is blown out of the rear.

Combine throughput limits on a level field are usually governed by the walker losses but during hillside operation, the shoe losses are the limiting performance factor. Furthermore on sidehill operation, grain losses become more significant as the sieves overload on the downhill side. To reduce these losses several alternative designs have been tried. The simplest is the use of several vertical fins mounted on the sieves in the direction of normal crop flow, which have become standard practice. For very steep slopes, hillside combines have been developed, mainly to reduce the risk of the combine overturning. The bodies of these combines will level automatically on side slopes of up to 40% and on up and down slopes up to 25%, during which the header will follow the ground contour. These units are rather complex and therefore expensive and are only justifiable in extreme terrain. In Italy about 20% of all combines sold are hillside units, whereas the market share in the whole of Europe is only 2% inclusive of the Italian market.

A simpler solution is the "uphill kit" shown in fig 10. This allows levelling of the combine manually or automatically for up to a 30% gradient for uphill work and up to a 5% gradient for downhill work. Another solution by John Deere for levelling a combine on hillside work is raising or lowering the drive wheels automatically by rotating the drop axle drive housings. In this manner up to 20% slope can be negotiated with the cutterbar following the ground contours. Newer developments only compensate for slope effects on the cleaning area. Sperry New Holland combines have a cleaning shoe complete with fan and grain pan, that is pivoted. This can compensate for gradients up to 17% automatically by means of an electrical actuator but the unit requires a specially built combine frame.

The Claas 3-D system will compensate for gradients up to 20% by altering the oscillation direction of the shoe as shown in fig 11. This effective and simple device can be fitted to the standard Claas combines as an option. It works on the principle of adding a third component to the shoe movement which imparts an adjustable horizontal sideways motion towards the uphill side. A lever connects the shoe with an adjustable mounting point on the combine frame which in turn is controlled by a hydraulically operated side arm. The control unit contains a pendulum and slide valve which regulates the oil supply of a hydraulic cylinder according to gradient up to a maximum of 20%.

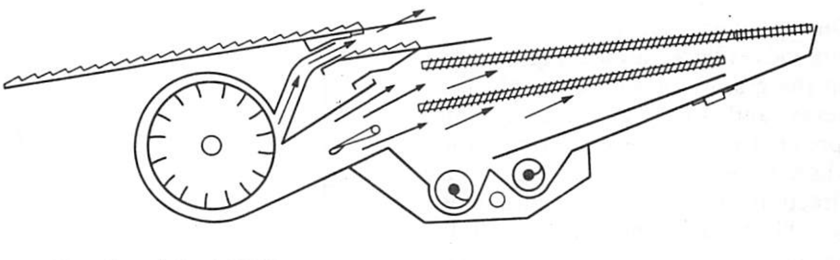


Fig 9 Ventilated double step grain pan

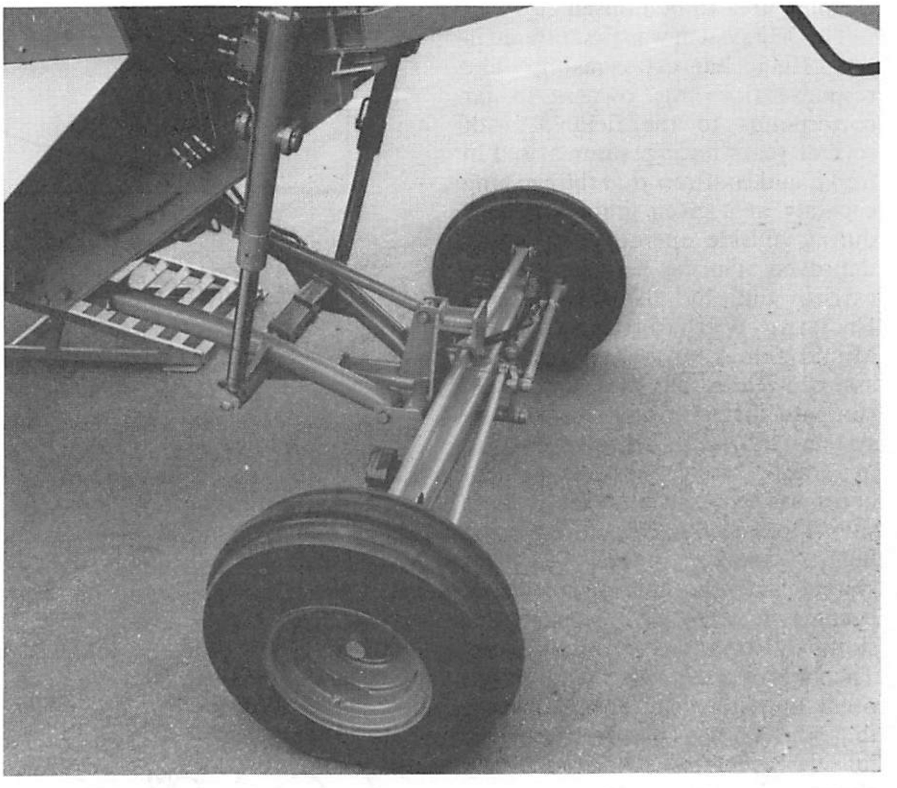
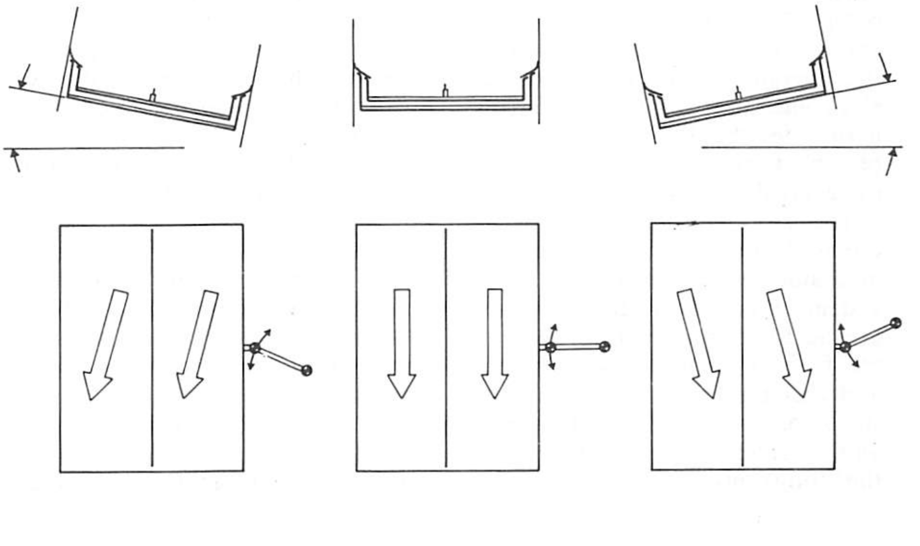


Fig 10 Uphill levelling kit fitted on combine

Fig 11 3D-cleaning system



During sidehill operation the sieve flux moves backwards along the fins on the grain pan and falls onto the sieves and the 3-D shoe motion spreads the influx evenly across the whole upper sieve area in the uphill direction. This even distribution is possible because there are no guide fins mounted on the 3-D sieves which enables the maximum capacity of the cleaning area to be utilised.

The 3-D system was first offered in the 1985 harvest season. The response from the owners so far corresponds to the field data of several years testing, summarised in fig 12, and confirms that the cleaning capacity at a given grain loss level during hillside operation is greatly improved. During a series of tests carried out by the Institute in Freising-Weihenstephan near Munich, three hillside systems were assessed. The results show that, if you compare the additional costs of the system with the potential reduction in grain losses, the 3-D system becomes economically feasible at side slopes of 4 to 5%, whereas the higher costs of the pivoted shoe system and the hillside combine, become feasible at much steeper slopes of 10 and 12% respectively. The improvements to the standard oscillating shoe cleaning system show that the known disadvantages on hillside operation can be nearly eliminated. New rotary cleaning systems that work independently of any sloping grounds are in the development stages at, for example, the University of Stuttgart — Hohenheim, but these developments are still at the experimental stage.

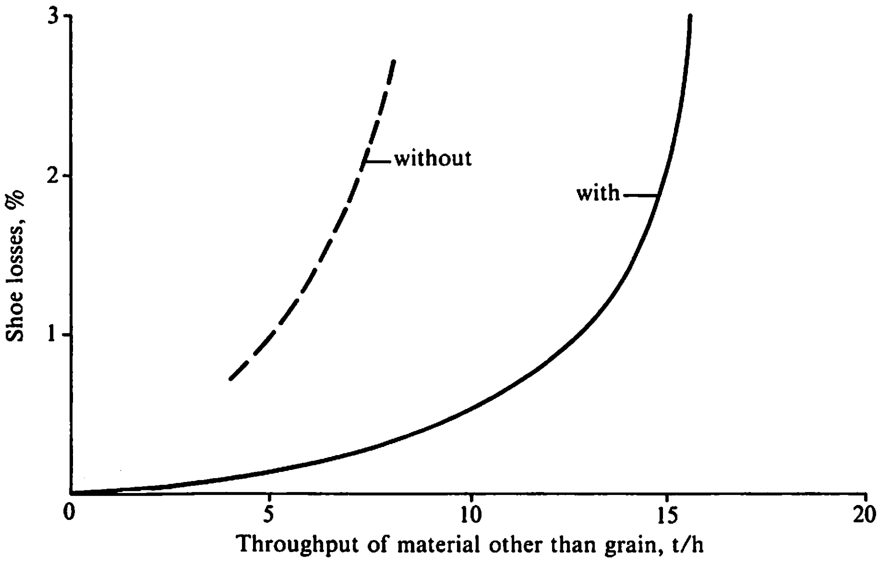


Fig 12 Combine shoe performance with and without 3D-system on 20% side slope

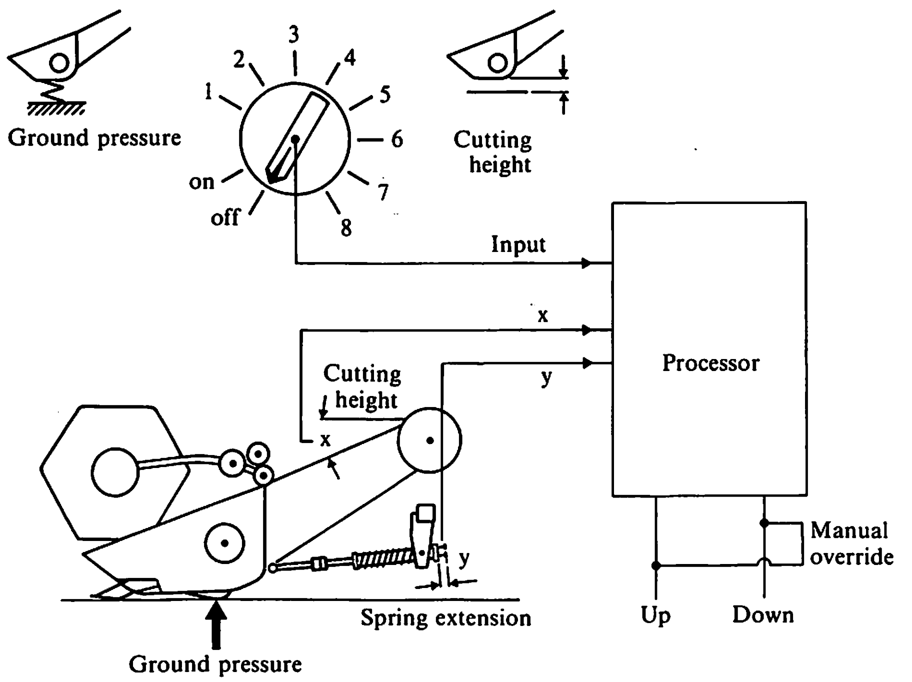


Fig 13 Automatic height and ground pressure control

Automation of the combine

The performance of a combine as a whole is governed by the efficiency of each component, nevertheless to optimise the performance of these components, perfect setting and control is required. To achieve this, the operator requires sophisticated electronic and automatic controls, using feedback systems where possible to relieve him from some of the control functions.

The automatic cutterbar height control measures the height mechanically by means of a feeler system. Problems with this system are that a minimum cutting height for the feeler system is always needed and that the header is subjected to shock loads for long periods because all the header weight is supported on the lifting rams, resulting in bouncing when travelling over uneven ground. To reduce these problems, a solution was sought to eliminate the vibration of the suspension springs by using a ground pressure control system so that the header would glide over undulating ground conditions. The ground pressure can be measured by either the hydraulic pressure in the lifting cylinders or in the extension of the suspension springs. The Claas-contour-system, shown in fig 13, utilises the spring extension measurement which reduces vibrations to a minimum and allows a very sensitive control; the ground pressure can be set at a minimum of 10% of the header weight. The operator has a choice of three cutterbar height adjustment systems with the Claas-contour-system, viz:

(i) manual height adjustment,
(ii) automatic height control with respect to the combine,
(iii) ground pressure control.

Automatic header height control enables some of the operator's attention to be concentrated on other functions of the combine.

Easy operation is also provided by an automatic steering system which has become a standard for all harvesting operations in maize crops. Automatic steering systems are in an advanced stage of development for cereal crops. A third step towards automatic control is a forward speed control unit which will operate in respect to grain losses at the cleaning shoe and the separation system.

As the time lag between loss sensing at the rear of the combine and adjustment of the feed rate is too great, the latter is sensed at the header by torque measurement of the intake auger which is then related to forward speed. Continuous feedback of the signals ensures a smooth adjustment of forward speed. Some reports do not view these systems with favour, but on the other hand, unit area harvested increases of up to 5% seem to be realistic. In addition, the chances of blocking the combine are minimised with these systems.

Some research projects are dealing with the automatic speed control of the reel, the fan and the threshing drum, but none of those systems is yet marketed in Europe.

Handling and service

The comfortable full view cab has become an integrated part of the medium and large size combines. Ergonomically designed cabs with easily reached and managed controls and a comfortable seat will keep the operator alert throughout a long day. Many control elements consist of electric-hydraulic or even electronic systems, so that the operator can control and adjust nearly all combine functions from the cab. The use of hydraulic remote controls avoids the need for mechanical components, thus reducing the transmission of noise and vibrations into the cab. Multi-function control elements increase the convenience of the operator and the larger combines have monitor systems installed. Shaft speeds of many components are monitored with an acoustic and visible alarm being given if these stop or speeds drop below a certain value. This alerts the operator before any major damage can occur to the combine. Grain loss monitors are offered by many manufacturers and other suppliers despite some known shortcomings of these units. Microprocessor based multi-function control units are offered in addition to the control monitors. These units will read all the major performance data and give a readout of unit area covered per hour or in total, and will remind the operator on service intervals.

Downtime due to service is reduced by either using non-greasable bearings or installing a grease point bank for easier service. A dust extractor unit, that utilises the vacuum from the engine exhaust, draws away dust frm the air filter and extends the intervals of changing the unit. Furthermore, relays, electric modules, fuses etc., are gathered into a central electric and electronic console which, together with well protected cables, ensure long term functioning of the electrical system.

Future developments

Future developments in combine engineering must be to optimise the economics of a combine by increasing the performance of the machine at the same as or less cost than at present. During today's harvest operation, actual combine capacity can only be utilised from 50% to 80% of the time, the remainder being used to move, service and set up the machine. Thus, there is a need to improve the design of the manouvreability of the unit, the size and unloading rate of the grain tank and the powertrain. The other priorities can be summarised as:

- high combine efficiency in a wide variety of crops as well as under difficult harvest conditions;
- minimising total grain losses both on level ground and on hillsides;
- producing high quality harvested crop without cracked or damaged kernels and with little trash;
- low specific power requirements;
- reduction of machine dimensions;
- reduction of combine weight.

Future improvements will include utilisation of microelectronics to optimise co-ordination of the combine components. The incorporation of advanced electronics for sensing inputs, processing information and relaying adjustments will have to be undertaken; the car industry sets guidelines in this area.

The alternative separation system combines will retain their market share in the high output combine class and no doubt further developments will occur. However, the larger proportion of customers are being well served with a wide selection of walker type machines. The walker type combine will remain the best and most economical machine for most customers for some time to come.

Straw chopping

H G Gilbertson and A C Knight

Summary

STRAW chopping is necessary as a pre-treatment to incorporation into the soil of residual straw from harvesting. Successful chopping reduces the length of straw avoiding long pieces of material fouling on cultivation and sowing implements. It also eases the mixing process with the soil and aids biological breakdown of the straw within the soil.

Studies have been made of the distribution of different lengths of straw pieces within samples taken from choppers in the field. Apparatus has been developed to give both a coarse length classification of a large sample, and, if required, a more detailed analysis of a sub-sample from within the shortest fraction.

Mechanical damage, crushing and splitting, inevitably occurs to individual straw stalks to varying degrees during both the combining and chopping processes. It depends on many factors concerned with both machine design and the condition of the crop. The nature and extent of stalk damage is believed to contribute to both ease of incorporation and rate of breakdown within soils. Methods are being developed to quantify damage in order to assess its contribution. Bulk density appears to be a useful measure of degree of total straw fragmentation.

A survey of combine-mounted choppers conducted by the Agricultural Development and Advisory Service (ADAS) and the Institute of Engineering Research has concluded that the choice of combine harvester type has a greater effect on straw length than choice of chopper type. Crop variety differences are also marked but to some extent masked by other crop variables present in the survey.

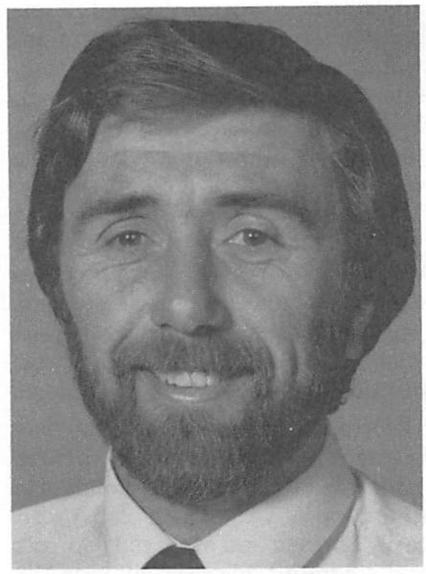
Power measurements, made on tractor powered choppers, indicate that the power requirement rises linearly with increasing throughput of straw.

Both the survey and separate trials at the Institute of Engineering Research have shown that crop throughput has no effect on chop length performance for either combine harvester or tractor powered choppers.

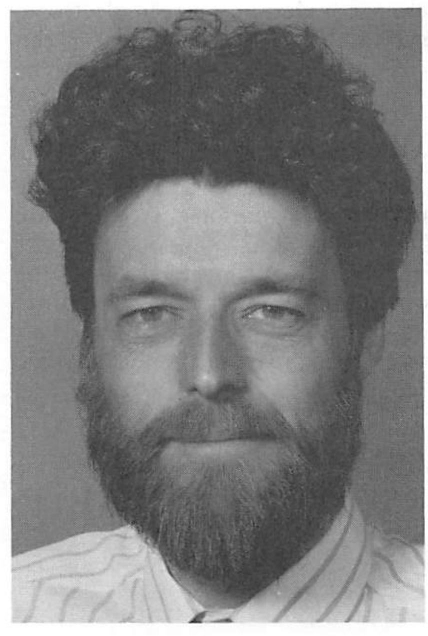
A new technique has been developed to allow an evaluation of chopping devices out-of-season. A 20 m long conveyor belt feeds the crop, which can be either fresh or stored, to a test rig or a complete chopper mounted at either end, or over the belt.

Two radically new designs of chopper are currently being developed. One gives a narrow band of chop length distribution with no long pieces to produce a more consistent chop length than is possible with a conventional chopper. It consumes approximately the same power as a tractor-mounted chopper for the same throughput.

The other is expected to give a very low power consumption, but requires favourable orientation of the crop to give a chop performance comparable to that from a conventional chopper.



Andrew Knight
Harry Gilbertson



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1 Introduction

Chopping, in the context of this paper, is a process to reduce the length of the straw so that it can be incorporated into the soil by subsequent cultivation.

Since chopping of any sort will entail some machinery cost and energy requirement, it is logical to first establish the minimum performance criteria.

Successful incorporation, using the minimum energy requirement can only be achieved if the straw is sufficiently and consistently short to easily pass between the soil crumbs, becoming evenly distributed within the soil profile to the full working depth. Incorporation, as opposed to complete burial, will nearly always leave a small proportion of straw on the surface. It is vital that however small this proportion, it must consist entirely of short pieces which will not foul further operations, particularly involving sowing equipment.

At present, short chopping is the only proven way to increase the rate of decay of incorporated straw (Harper 1985). Reduction in length results in better contact between the soil and the buried straw, and hence promotes decay of those constituent parts of the straw which are readily degradable.

In order to make a judgement of the effectiveness of a chopping mechanism, the characteristics of the chopped straw must be defined. The distribution of lengths in samples of straw from combine or tractor driven choppers can now be quantified by means of techniques and apparatus developed at the Institute of Engineering Research.

Existing choppers can be categorised as either those mounted at the rear of combine harvesters and driven from the combine harvester engine, or those mounted or trailed by tractors for use in a second pass across the field after combine harvesting.

Combine harvester mounted choppers have been the subject of a joint survey by ADAS and the Institute of Engineering Research on over 80 sites throughout England (Rutherford and Holden 1986). The performance of tractor powered choppers, in terms of both power consumption and chop length distribution, was evaluated in a number of separate trials which covered all categories, of currently available machines. One important aspect being studied at the Institute of Engineering Research is the physical properties of straw as a material. These already indicate that there are significant differences between varieties of winter wheat in terms of shear and tensile strength.

From these evaluations of existing machines and the more fundamental work on crop strength, two new approaches are currently being developed to satisfy two separate, yet complementary, requirements. The first is a chopper with a radically different geometry from that of conventional types to produce a much narrower band of sample chop length distribution. The second development employs the patented NIAE crop slicing principles as already applied to forage harvesting. This has the advantage of a lower power consumption.

The problem of having only a short season during which fresh straw is available in the field for testing and developing new devices has been, to a large extent, solved by the development of a swath simulator. Straw throughputs equivalent to the output from the largest available combine harvester can be simulated.

2 Chopper performance criteria

The three important aspects of the performance of any chopper are: length reduction, straw damage and power consumption.

2.1 Length reduction

The determination of crop length can be one of the most time-consuming operations in experimental work with fibrous materials. Until recently, the only reliable method was by laborious hand sorting of every piece within a sample. Mechanical sorting is an obvious solution, but a major problem with mechanical methods of sorting by length is the presence of bent and tangled material. The two items of apparatus mentioned in the introduction have been developed to sort dry material even when a proportion of the sample is bent and tangled.

The coarse classifier (Holden and Knight 1985), can cope with unchopped straw even when the length of some pieces approaches that of the original crop height (approx 700 mm), as well as chopped samples (fig 1). It can separate an 800 g sample in approximately 10 minutes. The material is fed from a box on to a reciprocating table which first consists of a corrugated section. Here the crop is aligned to its direction of travel. It next passes over or through a frogmouth sieve which has been calibrated to pass material of 50 mm or less. The longer material which has passed over the sieve next encounters a slot gate set to accept material < 120 mm in length. Finally, the longest material > 120 mm, passes off the end of the sorting table. Each of the three fractions is collected and the crop length distribution is determined by weighing and expressing each fraction as a percentage of the total.

The three fractions, representing those size ranges considered to present differing incorporating problems, were selected after discussions with agronomists, microbiologists and cultivation experts, namely:

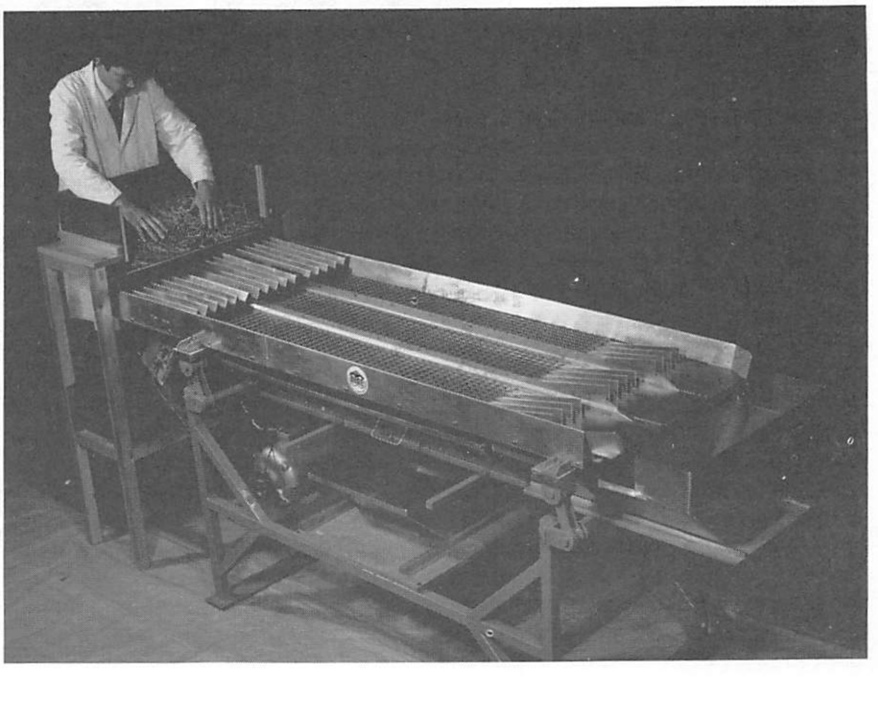
0–50 mm — generally agreed to present no problem to incorporating mechanisms;

50–120 mm — may present problems to reduce tillage methods;

over 120 mm — undesirable for any method other than ploughing.

A second apparatus (Gale and O'Dogherty 1982), has been designed for sorting chopped grass but is also appropriate for small, short samples of straw. This sorts into eight

Fig 1 Chop length classifier for long material



fractions divided to form a logarithmic progression from < 4.5 mm to > 90 mm, thus allowing a detailed analysis of the length distribution of chopped samples where the majority of the pieces are < 50 mm in length (fig 2).

The apparatus employs a curved diverging aspirator column in which turbulent air makes the sample move slowly upward and delivers individual pieces to the sorter. A double layer of cascading sorting trays separates the sample into the eight fractions.

Both items of equipment have been calibrated using hand prepared samples and ultimately checked against a hand sorted real sample.

Length distribution values from the apparatus are calculated on a weight basis and comparison with those obtained by hand sorting agrees within 5% of the median values. The distribution of lengths within a sample is best represented by the median length. This is defined as the mid-point on the distribution where 50% of the crop is shorter and 50% is longer. Although the median is the best measure of central tendency of this type of positively skewed distribution, it is also necessary to give some measure of dispersion about this point. This is best represented by the inter-quartile range (IQR) which is the dimension between the lower (25%) and upper (75%) quartile points on the cumulative undersize distribution curve, see fig 3. For example, in a sample where all the pieces are of similar length, the inter-quartile range will be small, whereas if the length distribution is broad, then the inter-quartile range will be large.

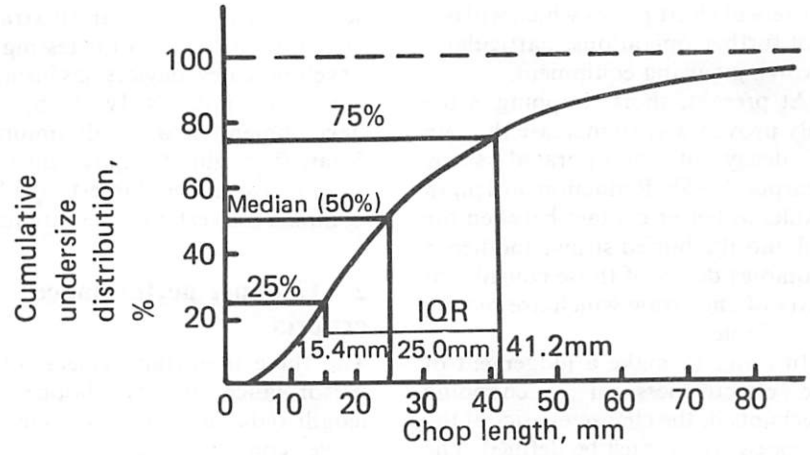
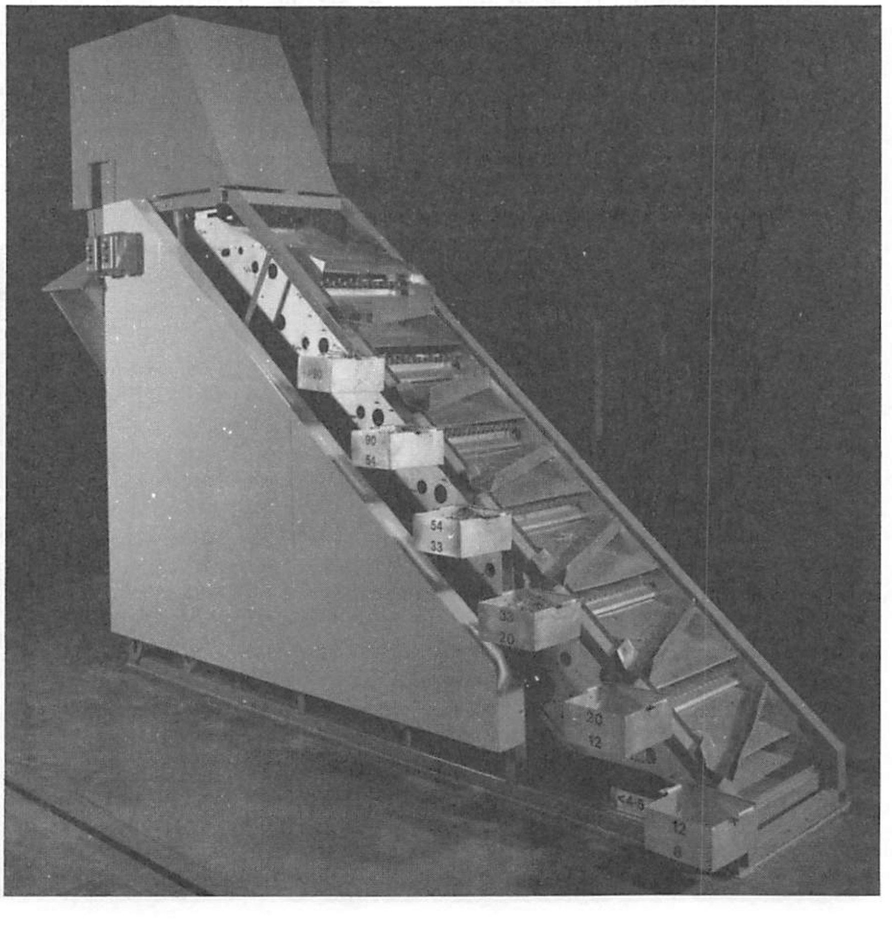


Fig 3 Typical chop length distribution curve

Fig 2 Chop length analyser for shorter samples



2.2 Power requirement

The power required for straw chopping can be critical in the context of combine harvester mounted choppers where an excessive requirement may constrain the performance. Choppers are becoming more common as an option on combine harvesters and the manufacturers are uprating their engines to cope with the increased power demand. No published data are available on chopper power requirement as measured directly on the combine harvester in work, although several attempts have been made to deduce this by indirect means.

One such indirect method (Freer 1985) is to measure total fuel consumed by the combine harvester engine using a precision fuel flow meter. Runs are conducted with and without the chopper engaged and, by relating fuel consumption back to the engine's performance characteristic curves, a mean power figure can be obtained. This, however, gives no indication of power fluctuations within the test period.

Another indirect method, as used by DLG, Germany, is to demount the chopper from the combine harvester and position it at the end of a conveyor belt. Artificially created swaths of straw can then be presented to the chopper intake by the moving belt. This allows much more control over crop factors, such as throughput and swath variability, but care must be taken in predicting, from these controlled results, the likely actual results if the chopper were on the combine harvester and in field conditions.

Instrumentation currently being developed at the Institute of

Engineering Research would be adaptable to any combine harvester and allow direct in-field measurement of chopper power requirement. Results from this equipment should give a much clearer picture of the torque and speed fluctuations as well as the mean power for varying crop throughput, moisture content, and species or variety.

Power requirement of tractor powered choppers is less critical, and operations are generally limited by either the maximum pto power output of the tractor, or more likely, the throughout capacity of the chopper. Measurement of pto power is much simpler than on a combine harvester and all results from work done over several years show power requirement to increase proportionally with throughput. Since power consumption rises linearly with throughput and since chop performance is unaffected by throughput for typical forward speeds, it is clear that there is no improvement in chop performance from operating at low throughputs.

Straw damage

In the chopping process, it is possible to perform work on the straw other than by length reduction. Indeed damage to the stalks is inevitable in most practicable choppers. This may take the form of splitting along the length of the cut pieces, crimping or kinking, flaying of the cut ends by tearing, or crushing of the stalk. These can sometimes be inflicted for a very small energy requirement and so are worthy of investigation. Observations in the field indicate that flattened straw will incorporate more easily, and tests are under way in liaison with the AFRC Institute of Arable Crops Research to quantify the benefits, in terms of accelerated decay of damaged straw, compared to intact straw of the same length. Techniques are being developed for quantifying the degree of physical damage in individual stalks. However, bulk density of the loose chopped straw has been found to be a consistent indicator of total straw fragmentation, ie length reduction and straw damage. Measurements have been taken of over 800 chopped and unchopped samples from the field; these have received different degrees of damage as well as having different length reductions. These differences can be due to machine variables such as combine threshing action or chopper design, or crop variables such as variety, maturity at harvest or moisture content of the straw. Typical bulk densities of unchopped samples can vary from 6 to 16 kg/m^3; straw chopped by conventional means ranges between 15 and 50 kg/m^3.

Work is continuing into establishing the limitations of bulk density measurement as a method for quantifying straw fragmentation. It may offer the possibility of a cheap, simple and effective field method of determining how readily a particular straw will incorporate.

3 Existing chopper performance

The problem of straw chopping is not confined to processing the efflux from the combine harvester, where minimal cultivation is required, it may also be necessary to reduce the length of stubble. Stubble can often be 250 mm high and represents the heaviest and wettest part of the plant. Measurements of straw moisture content within stalks, for example, reveal differences ranging from 15% wb at the ear to 60% wb at the base of the same plant. Lowering the combine harvester cutterbar to reduce stubble height may have the effect of reducing performance. This could be due to either the consequential need to reduce forward speed or the limits of the threshing and separating processes being reached due to overloading from the extra straw throughput.

A secondary cutterbar placed behind and lower than the existing one, appears to be the simplest practical solution. However, the slowness of uptake of this idea appears to reflect worries about the increasing complexity and reliability of the harvesting process.

3.1 Combine harvester choppers

The survey of combine harvester choppers undertaken by ADAS and the Institute of Engineering Research had the following objectives:

* to assess the effectiveness of the choppers;
* to measure the rate of work;
* to study the relationship between the rate of work and length of chop.

3.1.1 Method

The investigation was conducted solely in crops of winter wheat. Sites were selected to provide a clean, standing and healthy crop wherever possible. Five samples of chopped straw were taken, from each of two runs with the chopper engaged, using a 500 mm diameter catching net drawn across the chopper discharge to obtain a representative sample. Sampling from the ground is not satisfactory due to the likely loss of the smallest material, and the possibility of picking up the sieve discharge. The chopping mechanism was then disengaged and two further runs were made taking five unchopped samples from each run. The length of standing straw, stubble height and straw yield (swath weight per metre run) were recorded and samples taken for straw moisture assessment. The straw samples were classified using the apparatus already described.

3.1.2 Combine harvester type selection

The sample of combine harvester types selected for the survey was chosen to reflect their occurrence nationally. A feature of some of the recent designs of combine harvester has been that, in the process of improving threshing efficiency and capacity of the machines, the straw is subjected to much more severe treatment. Six separate types of combine harvester were identified in terms of the likely severity of treatment which their threshing and separating mechanisms would have on straw passing through them. Type 1 included combine harvesters employing only straw walkers, whilst Type 6 represented multiple drum threshing and separating machines.

3.1.3 Chopper type

Two makes of chopper are available in kit form to be fitted to most makes and models of combine harvester. Most combine harvester manufacturers now offer some form of factory fitted chopper as an option. All choppers in the survey were of a similar design. They consisted of a transverse rotor turning at approximately 3000 rev/min, fitted with freely swinging, sharp flails giving an effective diameter of approximately 500 mm, and hence, a typical cutting tip speed of 80 m/s. The rotor flails intermesh with a bank of static knives. The only adjustment for length of chop is the depth of engagement between the static knives and rotating flails, which each generally have an axial spacing of 25 to 30 mm. Thus, the spacing between the static and rotating elements at the point of cutting is 12 to 15 mm.

3.1.4 Effect of throughput

At four sites, extra runs were conducted with the chopper engaged at forward speeds 50% above and 50% below the optimum speed selected for the particular crop/combine harvester conditions. The chop length results showed no significant effect due to varying throughput. Analysis of the results from the rest of the survey where throughput varied from site to site and included other variation confirmed this finding.

3.1.5. Effect of crop maturity

Supplementary work to the survey was carried out at the Institute of Engineering Research into the effects of crop maturity by cutting crop within the same field at intervals over a six-week period from the immature grain stage through to over-ripe. No discernible trend was evident that maturity had any effect on chop performance.

3.1.6 Effect of variety

Many farmers have noted that some varieties appear to break up more easily than others. *Avalon* is often singled out as extremely easy to chop, with *Aquila* at the other extreme. From the survey, other differences are apparent. In 85% of the sites with *Avalon*, for example, the median length was <50 mm. Other varieties stand out as difficult to chop, but insufficient numbers in the sample preclude meaningful ranking of these data.

3.1.7 Effect of combine harvester type

The combine harvester mechanism had a marked effect on the degree to which the straw was broken when passing through the machine. Indeed, many farmers will have observed the different swath patterns from some of the more aggressive types of design. The results showed a trend towards a greater length reduction from Type 1 to Type 6. For example, for combine harvesters with straw walkers, the median length of straw input to the chopper, ie the output from the combine harvester, was double that of combine harvesters with rotary separation.

However, it is not possible to quantify confidently the effect due to the small number of newer types surveyed and the masking effect of crop variability between sites.

It is interesting to note that three variety/combine harvester situations without a chopper produced a shorter median length than the worst three variety/combine harvester situations with a chopper.

3.2 Tractor-powered choppers

A number of different trials have been conducted by the Institute of Engineering Research to investigate various aspects of the performance of tractor mounted straw choppers. These covered all categories of currently available machines. Conventional choppers with a horizontal transverse rotor and swinging knives comprise the majority in current use. They are mostly converted haulm and pasture toppers and can be used with a number of flail types and configurations to achieve different effects. The flail tip speed varies from 50 to 80 m/s depending upon make and model, and height control is generally achieved by means of adjustable skids or wheels. The two commonest types of flails fitted to these machines are the universal, or "J" shape, or the straight type flail which intermeshes with a static bank of similar shaped knives. Results from machines fitted with the universal type blade have shown that reductions in average stubble height of 50 mm are possible when the blades are set 60 mm from the ground and with an average stubble height of 170 mm. They can achieve a median length only 8 mm longer than that of a comparable machine having straight flails and static knives when working in the same crop. However, the latter machine achieves no stubble chopping.

Machines fitted with either straight or universal flails leave 10–15% of straw longer than 120 mm. Typical median values range from 45–60 mm. Effects of blade sharpness and crop moisture content have been investigated but only minor effects were found.

The power requirement of conventional machines is approximately 5 kW at no load, rising proportionately with increasing straw throughput. Typical total machine mean power consumption is between 30 and 45 kW for a throughput of 10 t/h. The average specific power requirement was found to be 3.7 kW h/t. These data are based on moisture contents of 15% wb.

As with combine harvester choppers, variation of crop throughput has been found to have no effect on chopping performance within a practical working range of 6–13 t/h of straw.

The use of forage harvesters, either of the flywheel or cylinder type, is quite practical but expensive in terms of work rate, machine wear, and power requirement for a given throughput when compared to conventional straw choppers. However, when set to a theoretical chop length of 20 mm, the sample median length is typically 30–37 mm and the percentage of long (>120 mm) material is less than 5% of the total sample.

3.3 Straw spreading

Ideally the sievings and the chopped straw should be spread as evenly as possible over the full header width of the combine harvester. Chopped straw is often poorly spread, especially in windy conditions. One problem of unspread sievings is that they contain the majority of weed seeds and failure to spread them can cause a concentration, which along with other factors such as nitrogen demand, can lead to noticeable striping in the following crop. The chopped material should be spread as evenly as possible over the full header width and apparatus has been developed for use this season to measure the spreading performance of choppers. This will assist in developing better spreading mechanisms which are less susceptible to wind effects.

4 New developments

The chop performance characteristics of conventional choppers have already been described and research is under way to investigate improved methods of chopping straw. An important feature of the positively skewed length distribution, typical of single rotor impact cutting choppers, is that they always produce a distribution with a long tail, ie a significant proportion of material considerably longer than the median is always present. This phenomenon is due to the cutting surfaces all lying in the same plane, while the straw enters tangled and completely disorientated. As a result, some straw is ideally orientated to lie across the cutters and hence will be chopped to the blade spacing. The bulk of the straw is at some angle between the ideal and the worst possible orientation, and hence the median is greater than the inter-blade spacing. A proportion, however, is always orientated at the worst possible angle, ie in line, or nearly so, with the cutting process and so is merely being conveyed through the machine with little chance of length reduction.

Current objectives are to develop a chopping mechanism which is capable of fragmenting straw to a median length of 35 mm, but with a very low proportion of short (<20 mm) and virtually no long (>120 mm) pieces. The current test rig, used to evaluate the principle, produces such a distribution with medians 25–30 mm. Taking into consideration the extra work done in producing this improved distribution, the power requirement is still comparable with conventional tractor mounted choppers. This much narrower band of chop length distribution is achieved by employing a radically different geometry from that of the conventional chopper, and is the subject of a patent application. Its potential lies not only with the chopping of straw for incorporation, but also with possible industrial uses where a consistent chop length is as important as the median length.

A second machine employs developments of the already patented NIAE crop slicing principles as applied to forage harvesting. This has the advantage of very low power consumption due to the efficient shearing of the straw at low speed and, hence, is applicable to mounting in a combine harvester where power consumption can become critical to the performance.

Both machines are still in the experimental stage and only exist as test rigs at this time.

One possibility where chopping is not to be carried out on the combine harvester, would be to raise the header cutterbar, leaving a deliberately long stubble, but allowing a faster rate of combine harvesting. The reduced amount of straw passed through the combine harvester could be spread unchopped, for little power requirement. A new stubble cutting/chopping implement could then operate with a primary cultivator in a second pass. The machine would not be constrained to following the combine harvester swath trail and would ensure treatment of the total volume of crop residue above ground.

5 Conclusions

Following extensive field work to collect straw samples from combine harvester and tractor-mounted choppers and with the development of apparatus to quantify the degree of straw fragmentation within the samples, it is now possible to assess the effectiveness of any chopping mechanism in straw. A study of existing chopper performance has revealed where improvements can be made, and work is in progress to develop radically new types of chopper which will overcome these limitations. As straw is a natural material, variability in its physical properties is present even within relatively small samples of a single variety. Techniques have been developed to allow more control over the effects of these crop variables so that development work on new mechanisms can be more rationally based. Two separate designs, both radically different to existing choppers, show potential and are being developed in test rig form.

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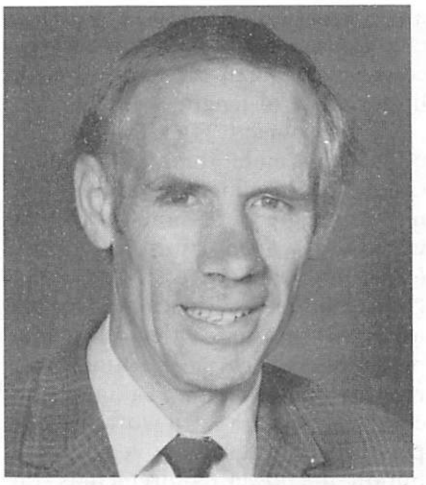
Straw compaction research

M A Neale



Summary

RESEARCH at the National Institute of Agricultural Engineering (NIAE) over the past one and a half decades into the compaction and packaging of straw is reviewed and the more recent findings on the making of high density bales and wafers are discussed in detail. High density bales require twice the force to compress the straw from a density of 200 kg/m^3 up to 300 kg/m^3 so that the bale may be tied with twine and yet relax to a density of 200 kg/m^3 without breaking the twine. Straw wafers have been made in closed-ended dies in a laboratory press and by a rolling process. Wafers so made have a relaxed density of 600 kg/m^3 and an acceptable resistance to fragmentation.

Commercial pelleting and wafering machines are reviewed and compared with the proposed NIAE machine at its present stage of development.

Introduction

High density packages reduce the handling, transport and storage costs provided the energy input to make such packages is at a cost-effective level.

In the early 1970's the first of the large balers became available, namely the Howard baler, followed by the first of the round balers. Although the packages formed were a single unit suitable for mechanical handling the density was less than that of a conventional rectangular bale of the time.

To investigate the possibility of increasing the density of these packages, a vertical hydraulic press with 2 m^2 platens and a 500 kN force capacity over a 1.8 m stroke was built. Large bales could easily be compressed to two to three times their original density, but when re-tied, the package was of an unacceptable shape from the point of view of stacking with only about a 20% increase in density.

It was concluded that to produce a high density package the straw should be pre-packed in the chamber in which high density compaction is to take place, or the compacting force applied in the same direction as that in which the crop was originally packed.

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Other programmes of research at this time led to a patented device for maintaining the maximum density on conventional balers and enabled them to achieve higher density bales consistently. However, the crop flow into a conventional baler running at 80 rev/min is such that 8 to 12 plunger strokes are required for each bale; bale movement along the chamber is rapid and uneven and makes density control by chamber friction very difficult.

A very-high-density bale compaction press (Klinner & Johnson 1977) was patented in the mid-1970's in which a conventional baler, without its knotters, was used to feed a column of straw into a densification chamber. When sufficient straw had entered the chamber, as sensed by a spring loaded plunger on the closed tail gate, a hydraulically powered sequence of events was actuated. A carriage carrying two sets of cleavers was powered rearwards by hydraulic rams, causing the cleavers to enter the column of straw and compress it into a volume of less than one third of the starting volume. The package was tied by conventional baler knotters with heavy duty twine and then ejected by opening the tail gate and engaging ejection wheels, whilst the cleaver carriage returned for the next charge.

This machine demonstrated the potential for making high density bales by a through-flow compaction system, but even at high density conventional bales are physically small and need complicated equipment for efficient mechanical handling. A study concluded that a bale of 1.2 x 0.6 x 0.9 m and weighing 130 kg (a density of 200 kg/m^3), would be more acceptable. Subsequent reactions of the farming community to demonstrations of such a package at agricultural shows have been very favourable.

Research then progressed to investigate the forces involved in making large high density packages with a view to designing a field machine. The vertical press previously described was used to compress packages of eight conventional bales, in two layers of four, to densities in excess of 300 kg/m^3. Compression between flat platens, supported by vertical bars, did not simulate the correct conditions and, therefore, an experimental horizontal press was built (fig 1). A chamber of nominal 0.9 x 0.6 m cross-section was swept by a piston through a 1.8 m stroke; a hydraulic ram of 150 mm in diameter provided the force of 400 kN at 22.5 MPa hydraulic pressure. The walls and top of the press were made so that the effect of chamber geometry on compaction force could be studied.

Subsequent information gathered from a range of tests with this equipment has enabled a manufacturer to build and test a prototype high density field baler.

A second approach to compaction of straw has led to research into the parameters involved in compacting uncomminuted straw into closed-ended cylindrical dies. A study of the effect of moisture content of the

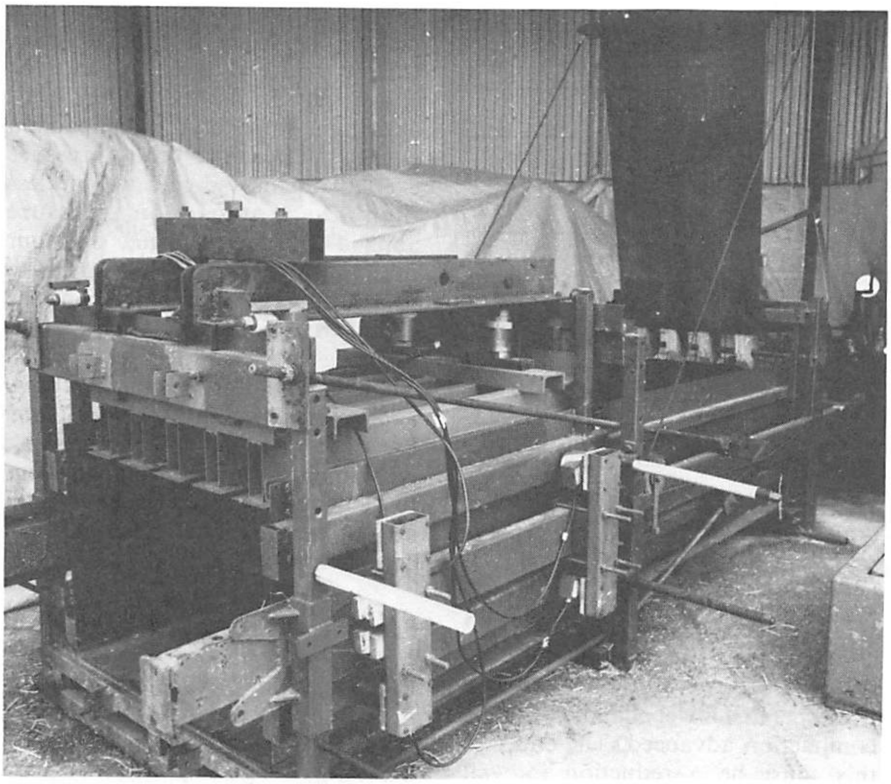


Fig 1 Horizontal piston press with tail gate removed

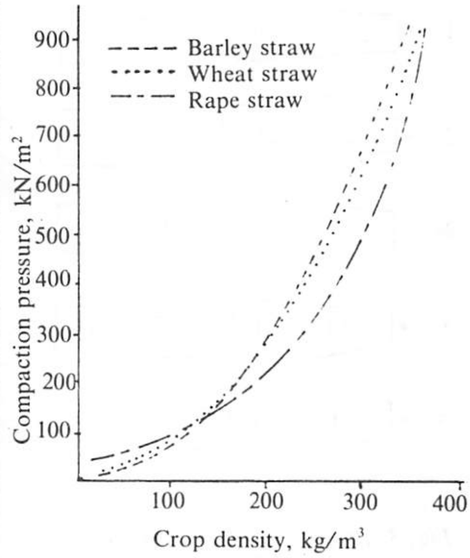


Fig 2 Comparison of pressure/density results

straw, die size and the mode of loading was made by O'Dogherty and Wheeler (1984) and resulted in wafers of 300 km/m^3 unit density after relaxing from 900 kg/m^3. Work then progressed to compacting straw into a rectangular die to make a wafer of relaxed density of about 430 kg/m^3. Doubling the compacting pressure gave very little improvement in relaxed density and the wafers were not very durable. Ribs were introduced to form high pressure areas and improve bonding and the durability of the wafer.

The objective of this research is to produce a field wafering machine with a throughput of 6 to 8 t/h. At this work rate, the most practical option is a rolling press which has the cells formed in the periphery of one or both rollers. A laboratory press has been built consisting of two 900 mm diameter rollers with cells formed in the circumference of one. A column of straw is fed into the nip between the rollers to form the wafers. This machine has a theoretical capacity of 1.4 t/h when powered by a 30 kW diesel engine and hydraulic transmission. At present it is being used to measure the forces involved, the effect of straw condition, and possible rates of work when making straw wafers. The results will provide data for the design of a field wafering machine.

Results of force measurement, during the making of high density bales

Compaction forces

Using the horizontal press (fig 1), the forces needed to compress straw to increasing densities were measured. Owing to the variable geometry of the press, the forces have been converted into pressures for comparative purposes. Maximum straw densities at the end of compression were in excess of 300 kg/m^3.

Throughout the 1984 season, the compaction pressures were measured in the horizontal press as the crops became available from the field. Wheat straw was expected to need the most compaction pressure and gave the compaction results plotted in fig 2. The data gave a regression coefficient of 0.980 for the equation:

$$P = 0.00528D^{2.05}$$

where P is the compaction pressure, kN/m^2,
and D is the maximum compressed density, kg/m^3.

Contrary to expectation, the barley straw results show that a slightly higher pressure was needed at the higher densities and gave a regression coefficient of 0.982 for the equation:

$$P = 0.00275D^{2.18}$$

It can be said that the pressure required to compact straw in a closed chamber to densities approaching 400 kg/m^3 increases approximately proportionally to the square of the density. This is an agreement with the results of O'Dogherty and Wheeler (1984) who found an index of 1.9 using a 50 mm diameter die.

Compaction results obtained with rape straw did not fit a power law well but gave a correlation coefficient of 0.993 for the expotential equation:

$$P = 36.98e^{0.00881}$$

These results are applicable to straw moisture contents ranging from 9 to 15% for the cereals and a single sample at 19.5% for rape. The variation in cereal straw moisture content within this range had no significant effect on the compaction pressures.

All the measurements in the horizontal laboratory press were made at a compression speed of 0.12 m/s. At this speed a field machine would have adequate time to perform a bale making cycle working at a rate of 12 t/h.

Compaction pressures due to chamber shape

Eight variations of chamber geometry were investigated, from diverging forms to parallel-sided; fig 3 shows the configurations investigated. The pressures to make bales to densities of over 300 kg/m^3 at maximum compaction increased by 10 to 15% as the degree of divergence was reduced from 2.9% to zero (a parallel-sided chamber) ie with increasing reference numbers, as shown in fig 3.

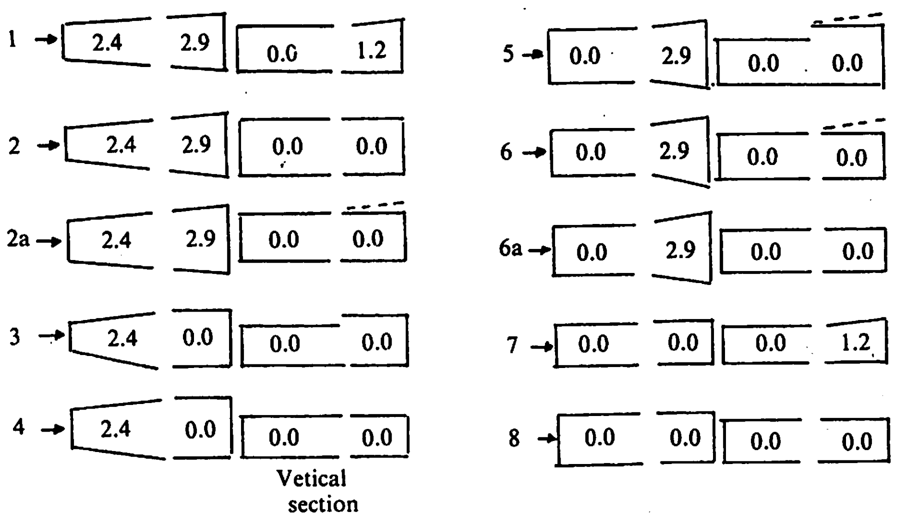


Fig 3 Press chamber configurations showing the percentage divergence of compacting and high density chambers (dotted lines indicate top of chamber released for ejection).

Vertical and horizontal pressures in the bale chamber

The pressures on the bale chamber walls were measured at maximum bale density in the vertical and horizontal planes relative to the line of compression. The vertical pressure was found to be always more than twice the horizontal pressure, due to the physical alignment of the crop within the chamber. The crop was loaded into the compression chamber in layers and pressed down horizontally, resulting in predominantly horizontal alignment. When compaction pressure was applied, the crop stems became predominantly aligned across the chamber and, therefore, expansion along this axis as compression increased was small. However, in the vertical direction, the compaction appears to cause individual straws to pack on top of each other and develop a vertical force considerably greater than the horizontal force.

In the bale chamber vertical pressures of up to 200 kN/m² and horizontal pressures of up to 95 kN/m² were measured. Their magnitude along the chamber decreased from the plunger end to the tail gate by as much as 90%. The design of the plunger face was found to be important. In the laboratory press, when the plunger reached the end of the compaction stroke there was at least a 30 mm gap between it and the chamber walls, allowing crop to squeeze back and exert more pressure on the chamber walls. However, in the earlier, smaller NIAE hydraulic press (Klinner & Johnson 1977), where shaped cleavers were used to intrude into the chamber from the outside through slots, the crop was forced away from the upper and lower chamber walls as compaction advanced. The effect of this must be a reduction in wall pressure and friction.

When the large bales were ejected from the chamber, the vertical and horizontal forces remaining in the bale caused it to expand by about 8% vertically and 2% horizontally.

Chamber friction forces

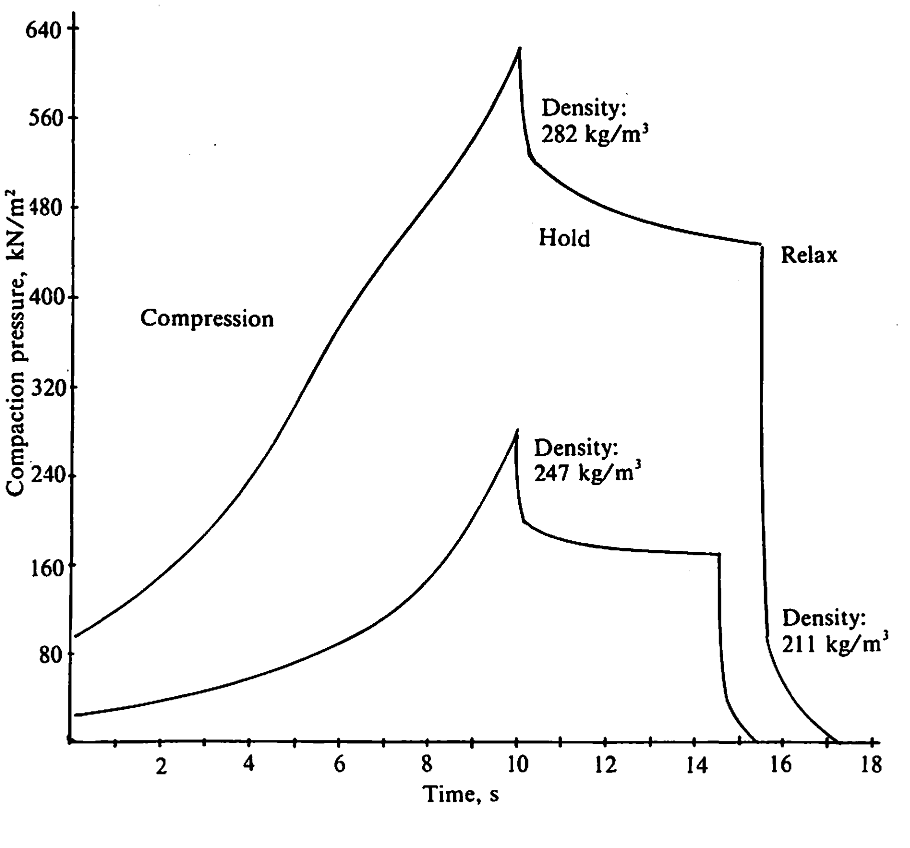
It has been shown that considerable pressures are generated perpendicular to the axis of compression when making a bale. In consequence, friction between the crop and the chamber walls is generated, absorbing some of the compaction energy. Therefore the pressure exerted on the tail-gate will be less than the compaction pressure applied by the plunger. In four experiments with barley straw, a mean tail-gate force of 75% of the compression force was measured. All the measurements were made in a chamber diverging horizontally only, and, apart from twine guides along the floor of the chamber, the walls were smooth. Different configurations or surface characteristics would affect the frictional resistance to compaction.

Forces to be restrained by the bale twines

Polypropylene twine is currently the most popular bale tying material and is readily available at various breaking strengths up to 2.8 kN. Wire was considered to be impracticable and also undesirable in the agricultural environment; therefore, the heaviest twine available was used. The tensile strength of the knot, however, is only about half that of that of straight twine (Klinner & Johnson 1977).

When straw is compressed in an enclosed chamber, the compaction

Fig 4 Typical compression-hold-relaxation curves for bales in an enclosed chamber



force increases approximately as the square of the density until linear movement ceases. At this point the reaction force exerted by the crop drops instantaneously to become constant at about 65% of the maximum applied force after around 3 seconds (fig 4). Retracting the plunger completely allows the reaction force remaining in the crop to fall to zero. A tied bale will not relax completely, so its rate of fall was measured by releasing the chamber sides and top clear of the bale and retracting the plunger in 10 mm steps, allowing the force to stabilise at each step before continuing. From a density of 290 kg/m^3, the bale will expand by about 150 mm in length, as well as a small amount laterally, to assume a final density of 200 kg/m^3, the residual force on the twines being about 10 kN.

Maximum density of the compressed package relative to final density needed to be greater by 50%, but the resulting twine tension was well within knot strength. However, it must be appreciated that in the laboratory press, compaction was slower than in a field machine, and it also took up to 10 minutes to tie and eject a bale, compared with 2 to 3 seconds. Therefore, the safety margin for the twine strength could be much closer than indicated.

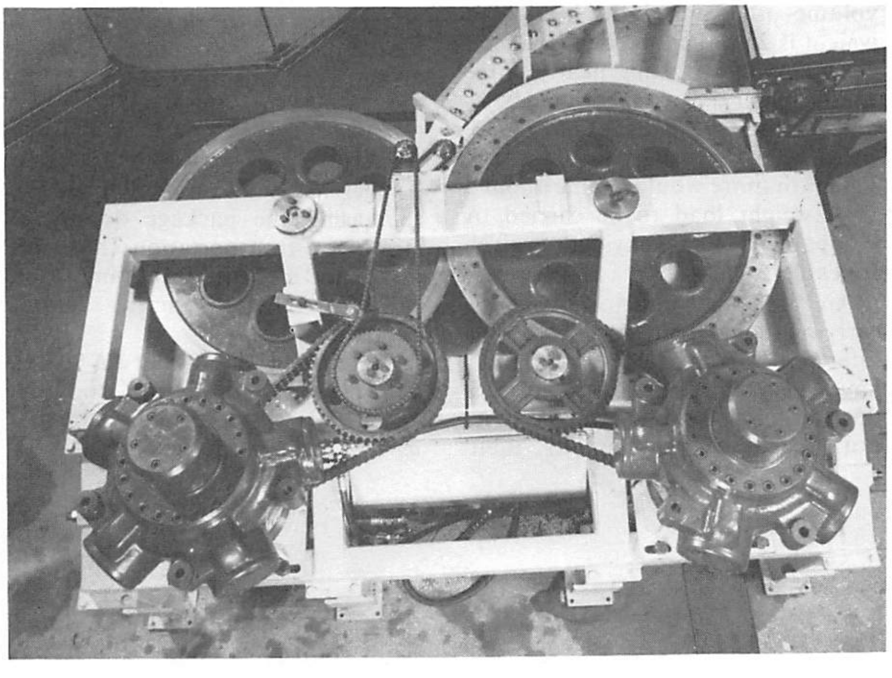
Force to eject bales from the chamber

Once a bale is formed and tied in an enclosed chamber, it has to be ejected before the next bale is compressed. It has been shown that the bale will expand up to 10% vertically and 2.5% horizontally so, ideally, the chamber should expand and allow the bale to eject by gravity. This however, may not be practicable with tying machanisms currently in use. Therefore, the force to eject bales horizontally from a diverging chamber was measured. It showed a steep initial rise up to 150 kN, associated with overcoming initial friction, followed by a gradual reduction after the bale started to move. The force measured was that needed to push a bale out of the chamber, with the inevitable slight bale compaction increasing the force required. If the bale was pulled out, the force would be less, but the tying bands would have to transmit the force to the front of the bale.

Results of wafer making experiments

Laboratory experiments to form rectangular wafers were conducted in a hydraulic compression test machine with a closed-ended die of 300 mm x 50 mm cross-section capable of compressing 300 g of straw. The first wafers were divided in the centre to form two 100 x 50 mm units with a relaxed density of about 430 kg/m^3. A force of 750 kN was required to produce this density; doubling the force, however, resulted in only a small increase in final density.

Fig 5 The NIAE laboratory wafer press



Where the wafer had been divided in half, a degree of mechanical bonding of the fibres had taken place. This was a most promising feature and initiated a series of experiments to determine the optimum geometry of die to produce a dense wafer from uncomminuted straw. Such a wafer would have high durability for transport and storage and have a high bulk density.

Over 20 different die shapes were examined and wafer density was progressively increased as improvements were incorporated. A unit density in excess of 700 kg/m^3 was achieved at a relaxation ratio of just over 3. An energy input of up to 40 MJ/t was needed to produce this denstity.

After achieving satisfactory wafer production in the small rectangular die, a larger die was made to explore the lateral as well as terminal division of wafers with parting elements on different faces of the die. Wafers made in both dies took up to 20 s to compress and 2 or 3 s to unload, so that the straw was held at a high density for a considerable time. At a nominal wafer weight of 100 g, to achieve a throughput of 1 t/h, it is necessary to make 10,000 wafers/h. With a target machine throughput of 6 t/h, it is necessary to make 16.67 wafers/s.

The most practicable means of making wafers at such a rate is in a rolling die with the wafers having the same attributes as those from the laboratory die. A preliminary study was made using a segment of a ring and roller press made to form six wafers whilst being rotated through 40° after the roller segment had been compressed into the ring by a 400 kN force from a hydraulic ram.

This experiment showed the feasibility of the principle and design went ahead on a laboratory roller press (fig 5), with cells formed in the periphery of one roller. To achieve a throughput of 1 t/h, the rollers rotate at 3.5 rev/min and each wafer takes 2.8 seconds to form. Strain gauges are used to measure the force between the roller shafts and the torque applied to the rollers is measured by hydraulic pressure.

The first wafers were of relatively poor quality compared with those formed in the test machine because in the rotating dies of the rig the crop was taken to its maximum density first at the loading side and subsequently at the trailing side, allowing material to extrude laterally across the wafer during compression. The resulting wafer was wedge-shaped and of low unit density.

Various cell shapes were examined until an acceptable wafer was produced. The forces between the roller shafts ranged up to 800 kN and the torque required to turn the rollers had maximum values to 22 kN m.

The maintenance of an even density of crop entering the press to ensure acceptable wafers is essential. This will form an essential aspect of investigations before the proposed field machine capable of a throughput of 6 to 8 t/h can be designed and built.

Review of current wafering presses

All the machines currently on the market are extrusion presses which require that the material to be processed is comminuted. The degree of comminution varies and, in many cases, additives are used to form sufficiently dense wafers.

The energy used to extrude straw, according to the manufacturer's specifications, varies from 80 to 200 MJ/t and throughput from 0.3 to 4.0 t/h. Table 1 lists the principal machines and their throughput and energy requirement; in addition to the energy needed to extrude the straw a comminution energy of 30 - 60% of the compression energy must be added. These presses are capable of producing pellets with unit densities up to 1000 kg/m³ or more, whereas closed-ended dies such as the NIAE experimental press can achieve 600 - 700 kg/m³ relaxed unit density at lower power input.

Table 1 Wafering and pelleting machines (packing phase only)

	Claimed throughput, t/h	*Claimed energy consumption, MJ/t*
Extrusion presses		
Bavaria	0.3	160
ECO	1.2	90 - 135
Bootham North	4.0	90
Desmi	2.0	90 - 120
Ventec (Prototype)	0.5	54
Bernewode (Prototype)	2.0	215
Closed die presses		
Howard		
NIAE		30 - 50

The Bavaria, ECO, Desmi and Ventec machines use the principle of a piston forcing the crop through a tapered or controlled die, output is limited unless multi-cylinder versions are used. Ring and roller dies, as used by Bootham North, Bernewode and the principle of the NIAE rolling press would require extra width to increase the throughput. In either type, speed is governed by the quality of the wafer produced.

Table 2 Typical payloads using a 12 m flat bed trailer

System	*Bale dimensions, m*	*Bale weight, kg*	*Payload* No per load	*Payload* Weight t
Conventional	0.36 x 0.46 x 0.95	16	512	7.0
Round	1.2 x 1.5 diameter	210	23	4.8
Large square	1.2 x 1.33 x 2.5	550	20	11.0
Vicon HP5600	1.6 x 0.7 x 1.2	200	64	12.8
High density	1.2 x 0.9 x 0.6	130	132	17.2

Transport and storage of high density packages

The cost of transport is a large component in the final cost of straw to the user and is a major factor encouraging current research into densification of straw. A modern road transport articulated lorry trailer of 12 m length has a load volume of 85 m³. If its legal load weight is 25 t, the load density could be up to 290 kg/m³, nearly three times greater than conventional bales and almost double that of most large bales. A high density package at 200 kg/m³ or more would enable about a 70% weight load to be carried. A comparison of bale payloads is given in Table 2.

An important factor in load carrying considerations is that of safety. A full load of straw would have a very high centre of gravity on a flat bed lorry and it may be prudent not to load vehicles to their maximum if high density bales became the norm.

Pellets and wafers on the other hand have a greater bulk density and would be handled in a bulk handling vehicle with rigid sides and could be tipped and conveyed like any other bulk-handled solid.

Straw made into high density packages will need to be of top quality before packaging and as such should be treated with care. This is especially the case for wafers which should not be allowed to get wet or they will expand and disintegrate.

Conclusions

Research at the NIAE has given a lead in solving the problems of improving bale density control and in increasing the density of conventional bales in an experimental compactor by a factor of more than two.

Trials with a prototype machine have shown that the principles developed would work equally well for a larger size of package.

Making straw pellets by extrusion requires a high energy input in addition to the need to comminute the straw first. Research is progressing on the development of a closed-die press to package whole straw, using one third of the specific energy used for extrusion.

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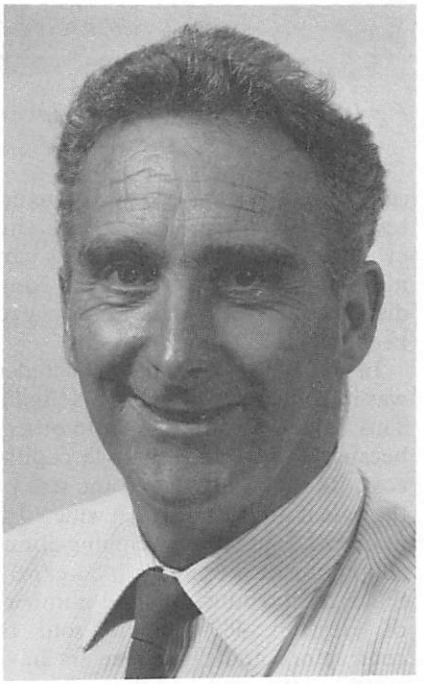
Straw densification for transport and use: baling and handling straw

D A Bull

Summary

THIS paper comments on the development of balers, including the recently announced high density machines. Traditional balers make bales which can be lifted and carried by users without excessive physical effort. More recent developments have been to produce bales which in themselves are unit loads, handled exclusively by mechanical equipment. The costs of baling and handling straw are discussed in detail, including the transport of straw on lorries.



Introduction

Between 5.5 and 7.5 million tonnes of straw are baled in England and Wales each year. Most of this straw is used on the farms where it is harvested, or at least in the same locality, but because the most prolific areas of straw production are in East Anglia and in Lincolnshire, inevitably some is transported westwards.

The main uses of baled straw are on livestock farms for bedding and for feed. The remainder, less than 1 million tonnes per annum, is used in various ways:

in horticulture for the production of mushroom compost and for crop production;
as a fuel in the form of bales or briquettes;
in industry or the manufacture of building boards.

For most uses the straw requires to be bright, clean and dry, and it is always an advantage if the straw bales are uniform and well made.

Baling and bale handling systems

The operations of baling and bale handling should not be thought of as separate tasks but as complete systems.

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A well planned system will:

- have an adequate work rate to clear the target area of straw to be baled;
- fit the manpower available;
- match the farm type or contractor's services with respect to field sizes, slopes and haulage distances;
- be reliable and easy to manage;
- be economic to operate

Balers

There are some 80,000 traditional balers working on farms in England and Wales. In addition, there are at least 8000 balers producing round or rectangular shaped bales which are handled exclusively by mechanical equipment.

Developments in baler design have been influenced by improvements in mechanical handling equipment and by the increase in tractor power.

Early designs of balers were often driven by threshing machines. One such baler was manufactured by Fisher Humphries. It used wire ties and was capable of producing straw bales weighing in excess of 60 kg each. Another baler, the Jones Invicta, was self-propelled, whereas other makes were towed but powered by their own engine. However, it became the norm to power balers from the tractor power take-off.

Traditional balers now produce straw bales dimensioned typically 457 mm wide x 356 mm deep x 1100 mm long, weighing about 18 kg (density 100 kg/m^3) with a work rate of about 5 tonnes/hour. In fact, a package which is easy for a person to lift and to carry.

Development

In the early 1970's there were 3 developments in baler design which were of special significance.

The Howard Rotavator Company Ltd took on the production of a baler which was developed by a Gloucestershire farmer, Mr Pat Murray. The Howard baler, as it became known, made bales dimensioned approximately 1.5 m wide x 1.5 m deep x 2.4 m long, weighing about 350 kg in straw (density 65 kg/m^3). These bales were handled mechanically throughout.

At about the same time, Farmhand (UK) Ltd imported the Vermeer baler which made a cylindrically shaped bale dimensional approximately 1.5 m wide, 1.7 m diameter, weighing about 300 kg in straw (density 88 kg/m^3). Material entering the bale chamber was rotated between 8 belts and on completion the bale was wrapped by twine — not tied. Field clearance of straw in round bales can be rapid using

Fig 1 The Hesston 4800 baler makes a 500 kg straw bale

Fig 2 This Massey Ferguson MF5 baler produces a bale 800 m square in cross section

inexpensive tractor-mounted handling equipment, but the cylindrical shape of the bale is not ideal for transport over long distances and the bales are not easy to keep dry in outdoor stacks.

In 1978, the Hesston 4800 baler was introduced to UK farmers (fig 1). This baler was different from others because of its relatively high capital cost, its high output and the size of the bale it produced, 1.2 m wide x 1.2 m deep x 2.4 m long, weighing about 500 kg in straw (density 145 kg/m^3). Since its introduction, the numbers of Hesston 4800 balers sold to contractors and large farmers have steadily increased and there are now some 200 in use.

Advantages claimed for high density balers include high seasonal outputs and the potential for easy bale handling. Baler manufacturers are aware of these advantages and at least 5 new high density balers have been announced recently. These are detailed in the Appendix. Two of them are shown in figures 2 and 3.

Fig 3 Three bales are accumulated within the Weger Delta 5000 baler

High density balers cost in excess of £30,000 each, so it is important that they are fully utilised to minimise the cost of each tonne of straw baled (fig 4).

The cost of baling and handling straw

The major cost components when operating a baler are:

1. ownership;
2. twine;
3. tractor;
4. operator.

Additional costs are incurred when the bales are handled. Traditional bales are usually handled in groups of 8, in flat formation; high density bales singly or in pairs.

Tractors and flat bed trailers are commonly used for the local transport of bales but special purpose bale transporters are also available for this task. These machines are designed to self-load and to off-load pre-arranged stacks, handling typcially 48, 56 and 120 traditional bales or 8 high density bales at one time.

Lorries are sometimes used to collect bales of straw direct from the harvest fields, but more usually they are used for long distance transport, in which case they are loaded direct from headland stacks or barns at regular intervals throughout the year.

Estimated costs of baling

The following calculations based on the use of 4 different types of high density balers highlight factors which influence straw baling and bale handling costs.

Balers identified as A, B and C are chosen as examples of high density balers whereas baler D (fig 5) produces high density bales of traditional shape. Details of the

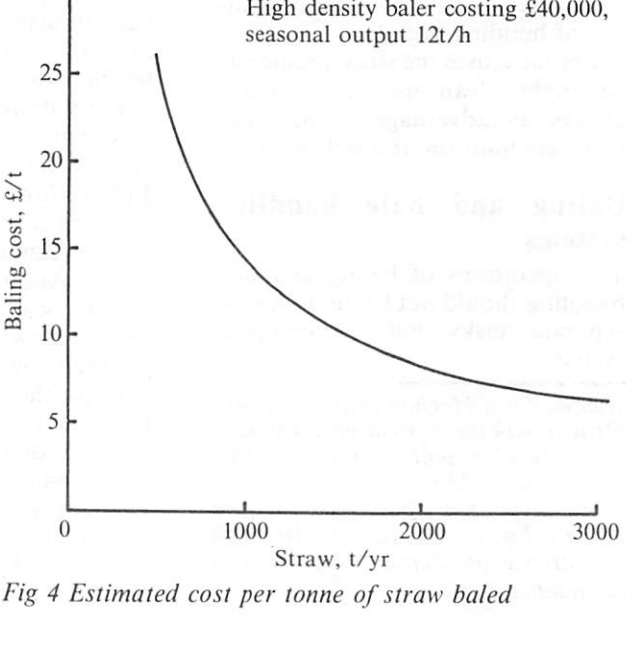


Fig 4 Estimated cost per tonne of straw baled

Fig 5 Traditional high density bales.

balers are shown in table 1. The relative dimensions of the bales which the balers produce are shown diagramatically in fig 6. It is recognised that bales made by baler B can be made longer than 1215 mm.

Costs are based on the prices of new equipment and the operators are costed over 300 hours, ie 50 hours more than the balers are actually working.

Assumptions:
baler life 4 years;
baling season 250 hours.

Costs of ownership, operator, tractor and twine, expressed as percentages of total baling cost/tonne are shown in fig 7.

Baler D shows a different pattern of cost relationships, mainly because the baler is less expensive than the others and it is baling less bales per season.

Table 1 Cost/tonne of straw baled: 4 types of baler

	Baler A	*Baler B*	*Baler C*	*Baler D*
Price, £	39950	31900	38950	10485
Bale dimensions, mm				
width	1220	800	1200	490
depth	1295	800	400	360
length	2438	1215	2438	1295
Straw bale weight, kg	500	120	194	30
Straw bale density, kg/m^3	130	154	165	131
Number of twines/bale	6	4	5	2
Overall baling output, t/h	12	10	12	5
Cost/tonne, £/t	6.63	6.45	6.70	6.76*

**includes the cost/tonne for use of a flat 10 accumulator*

Estimated costs of handling and transporting bales

The estimated costs of handling and transporting bales produced by balers A, B, C and D from harvest fields to headland stacks are shown in table 2.

The length of the bale (1215 mm) produced by baler B in this costing exercise results in a relatively high number of bales per hectare (37). There would be a good case for using an accumulator to group these bales behind the baler.

Assumptions:
Average journey time of 7.5 minutes (one way);
handling performance — loading single bales or groups of bales distributed about the field as left by the baler at 40 cycles/hour overall;
— offloading and stacking bales at 34 cycles/hour overall;
handling team — an operator, tractor and heavy duty loader fitted with a bale grab costed at £12/hour;
— an operator, tractor and bale trailer (12 m platform) costed at £11/hour.

The costs are based on handling the number of bales produced by each baler working at its overall baling output for 250 hours.

Estimated costs of baling, handling and transporting bales

The total estimated costs for baling, handling and transporting straw to headland stacks are shown in table 3.

Fig 6 Bales A, B, C and D

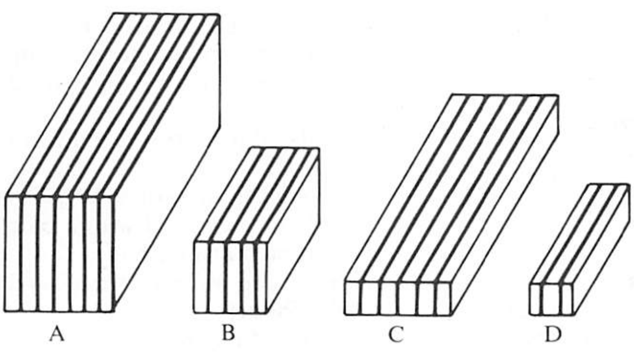


Fig 7 Costs of ownership, operator, tractor and twine expressed as percentages of total baling cost/tonne

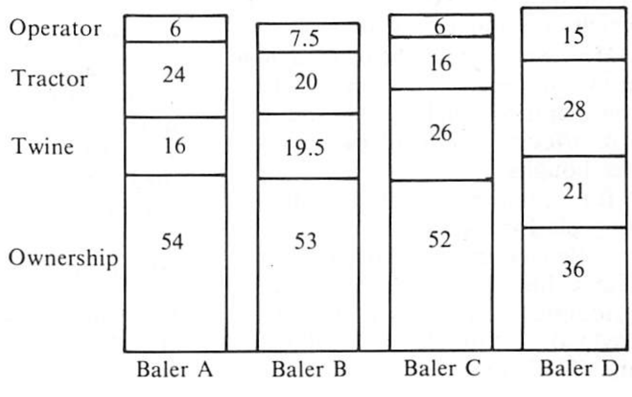


Table 2 Estimated costs to handle and transport bales produced by balers A, B, C and D from harvest fields to headland stacks

	Baler A	*Baler B*	*Baler C*	*Baler D*
Number of bales or groups of bales/ha in a 4.5 t/ha crop (to nearest whole number)	9	37	8	15
number of bales in a group handled at one time — Loading	1	1	3*	10**
number of bales in a group handled at one time — Offloading & stacking	1	2	3	10
Trailer load, t	10.0 2 bales high	10.8 3 bales high	11.6 6 bales high	9.0 6 bales high
Weight of bales in each group, kg	500	120 and 240	582	300
Cost/tonne of straw handled, £/t	3.06	8.12†	2.65	4.80

**Accumulated in the baler*
***Flat 10 accumulator*
†*2 teams are required to complete the handling operation within a reasonable time.*

Table 3 Estimated costs to bale, handle and transport bales to a headland stack

	Baler A	*Baler B*	*Baler C*	*Baler D*
Baling, £/t	6.63	6.45	6.70	6.76
Handling and transport, £/t	3.06	8.12	2.65	4.80
Total, £/t	9.69	14.57	9.35	11.56

Transporting straw bales on lorries

The payload space on a lorry depends on the width of the lorry platform, the platform length and the load height. Whereas platform width is usually 2.5 m, the platform length depends on the type of lorry, for example:

articulated trailer 12.2 m;
rigid lorry 7.3 m;
rigid lorry + trailer 7.3 + 6.7 m.

If the payload space is to be fully utilised, it is important that the full use is made of the load height.

In the United Kingdom, there is apparently no height limit for loads except in two cases: public service vehicles, which are limited to 4570 mm, and articulated vehicles where the laden weight of the articulated combination exceeds 32,520 kg which are limited to 4200 mm.

However, the height of a payload may depend on practical considerations such as load stability, low bridges, overhead cables, even tree boughs.

If it is assumed that the height of a lorry platform above the road is 1370 mm, then taking the restricted overall height limits mentioned above as guidelines, maximum height of payload = 4570 - 1370, ie 3200 mm, and 4200 - 1370, ie 2830 mm.

A further indication of heights of payloads used in practice are: 8 layers of traditional bales = 2880 mm, or 9 layers = 3240 mm.

Bale density

The bale density required to achieve a full payload can be estimated for individual cases.

For example, if an articulated lorry, 21 t payload, is used to transport straw bales, it can be assumed that the payload space is 2.4 m wide x 12 m long x 2.88 m high, so the density required to achieve a full payload is 253 kg/m^3.

Balers do not normally achieve densities as high as 253 kg/m^3 and it becomes clear why most lorries hauling straw operate at less than 60% utilisation.

There are one or two straw contractors in England using bale densifying equipment. Traditional straw bales are compacted and tied in a stationary press to about one-third of their original length, and Hesston 4800 bales are compacted to half their original length. The cost of this additional densification is said to be worthwhile for long transport hauls, especially if the straw is exported.

Lorry haulage charges

It is difficult to be precise about the cost of transporting straw. The cost depends on a variety of factors including local circumstances, tonnages of straw to be transported, the road network, and back loads. Some straw merchants view transport costs as part of an overall straw supply package.

A useful reference for haulage costs is provided by the Home Grown Cereals Authority (fig 8).

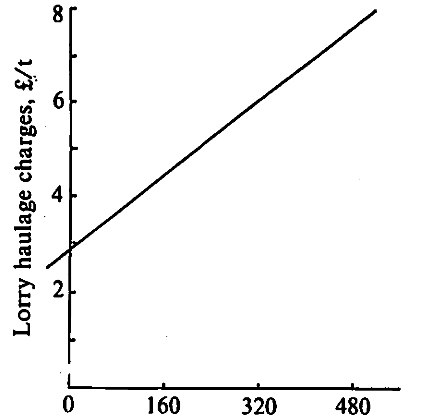


Fig 8 Average charges for hauling grain 1985
Source: Home Grown Cereals Authority

The costs per tonne in this case relate to lorries carrying maximum payloads, ie 100% utilisation.

The cost of transporting straw on lorries

A lorry load of straw is made up of a number of load units. The shape and weight of each load unit is determined by the dimensions of the bales and whether or not the bales are handled in groups.

For example, a load unit might be a single high density bale or a group of traditional bales.

The following costing exercise is based on a hypothetical case to show how the cost per tonne of straw transported is affected if a 14 tonne payload is made up of either 25, 50 or 100 load units.

Assumptions:

overall handling performance loading a lorry when collecting bales from headland stacks at 42 cycles/ hour;
overall handling performance offloading lorries and stacking the bales at 36 cycles/hour (hard standing);
articulated lorry trailer platform length, 12 m;
an operator, tractor and heavy duty loader is fitted with a bale grab costed at £12/hour;
a driver and waiting lorry costed at £12/hour;
lorry cost/mile 80p.

Table 4 Cost/tonne (£/t) to handle and to transport straw based on 14t payload

No of units making up the 14t payload	*Handling and transporting cost, £/t Return journey distance, km* 80	160	240	320
25	5.07	7.93	10.79	13.64
50	7.27	10.13	12.98	15.84
100	11.71	14.57	17.43	20.29

Table 4 shows the estimated cost/tonne to handle and to transport straw over four different journey lengths when a 14 tonne payload is made up of:

25 load units of 560 kg each;
50 load units of 280 kg each;
100 load units of 140 kg each;

The results are shown in fig 9. When the round trip journey is 80 km, the cost/tonne is more than halved by reducing the number of load units to be handled from 100 to 25. There are savings even at the 320 km round trip journey.

Similar calculations are used to estimate the cost/tonne of straw transported when hauling loads of bales produced by balers A, B, C and D as described previously.

Payload details

baler A — 20 bales to make up a 10 t payload;
baler B — 60 groups of bales (handled in pairs) to make up a 14.4 t payload;
baler C — 30 groups of bales (handled as 20 groups of 3 bales each topped up by 10 groups of 2 bales each) to make up a 15.5 t payload;
baler D — 45 groups (handled in flat 10's) to make up a 13.5 t payload.

These results are shown in fig 10.

In table 5, the least cost is £4.97/tonne when a 15.5t payload made up from 30 load units is transported over a total journey distance of 80 km, whereas the most expensive cost shown is £18.48/tonne, a 10 t payload made up from 20 load units transported over a total journey distance of 320 km.

The above examples show how bale density, bale dimensions and the number of bales handled as a group have an effect on the cost/tonne of straw transported,

For any chosen payload, the fewer the number of load units to be handled on and off the lorry, the better, although the load unit weight is restricted in practice by the lifting capacity of farm loaders (500–600 kg weight of material is about the optimum weight which can be handled at one time on the majority of farms).

There may be some reluctance on the part of straw users to accept high density bales, especially on those farms where traditional bales have always been used. It will fall to the manufacturers of high density balers, and to others, to educate users of the bales about how best to take full advantage of the unit load handling concept.

Table 5 Estimated cost/tonne (£/t) for transporting straw baled in balers A,B, C and D over 4 different journey lengths

Baler	*Payload, t*	*Handling and transporting cost, £/t Return journey distance, km* 80	160	240	320
A	10.0	6.48	10.48	14.48	18.48
B	14.4	7.94	10.72	13.50	16.29
C	15.5	4.97	7.55	10.13	12.70
D	13.5	7.09	10.06	13.02	15.98

Fig 9 Haulage costs – same payload but different numbers of units handled

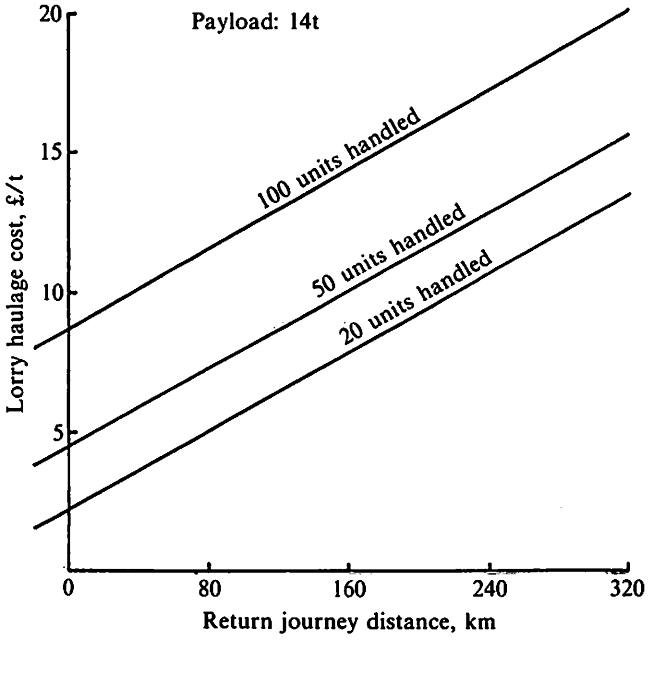
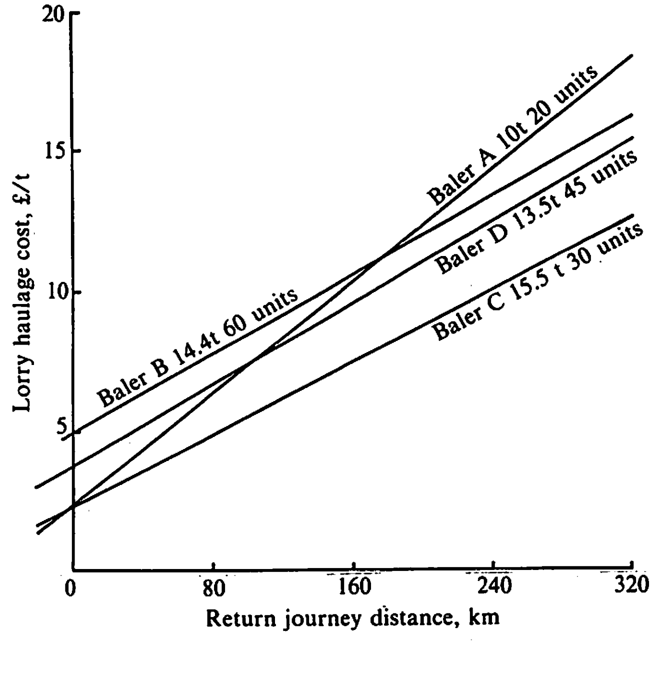


Fig 10 Haulage costs – transporting bales produced by balers A, B, C and D



In the future, it is likely that buildings to house livestock will be designed to allow unrestricted movement of equipment which is used to handle high density bales.

Conclusions

1. Traditional balers have been developed to produce bales which can be lifted and carried by users without excessive physical effort.
2. To keep baling costs at a competitive level, high density balers, because of their relatively high cost, should be used to their full capacity throughout the harvest season.
3. The weights and dimensions of straw bales will determine the number of bales to be moved for each tonne of straw handled, which in turn influences the cost of handling the bales when clearing fields, loading/offloading transport vehicles and when making stacks.
4. If the dimensions of high density bales are such that lots of individual bales are left behind the baler, there is a good case for using an accumulator behind the baler to form the bales into groups.
5. The width and depth dimensions of a bale will have an effect on the ability to make full use of lorry payload height.
6. It may be necessary to educate users of traditional straw bales about how to make the best use of high density bales. This applies especially in livestock areas where it is likely that future designs of housing for livestock will provide unrestricted access for equipment used to handle high density bales.

Acknowledgements

Permission to present this paper was given by Mr M Jamieson, Senior Mechanisation Adviser, ADAS, and the author also wishes to acknowledge the helpful comments made by Mr E Audsley, NIAE.

Appendix High density balers (information from manufacturers' brochures)

	Bale dimensions width x depth x length, mm	*Bale weight in straw, kg*	*Tying*	*Strokes/min*	*Pto, kW*	*Price, £*
Hesston 4800	1220 x 1295 x 2438	500	6 twines	26	110	39,950
Hesston 4700*	800 x 850 x 1600	175-200	4 twines	39	80	32,000
Welgar Delta 5000*	1200 x 400 x 1500-2500	80-200 Accumulated x 3	5 twines	70	80	38,950
Massey Ferguson 5	800 x 800 x 900-2500	110-225	4 twines	46	70	31,900
New Holland D1000	600 x 900 x 1200-2500	100-200	4 twines	46	70	To be announced
Vicon HP1600*	1600 x 700 x 1200	200	4 wires	6-8	80	35,500
Freeman 1500*	1168 x 965 x 1200-2500	430	6 twines	30	90	49,950

** Advertised as being suitable for baling silage*

Radiant heat treatment of cold stored onions to avoid condensation during market preparation

W F Maunder and C F H Bishop

Summary

TO avoid condensation and quicken response to the market requirements, a method of in-line radiant heaters to warm the skin of the onion as they reach the grading line was developed and evaluated. The work showed that onions exposed to at least 30 seconds of high temperature radiant heat achieved a surface temperature above the dewpoint and that the onset of condensation was delayed and often avoided.

Introduction

Long term storage of onions is carried out at -1°C to 1°C and condensation of water vapour can occur on the surface of the bulbs when the onions are transferred from the store to a warm packhouse. During the normal packhouse processes when onions are topped, graded and packed in preparation for sale the condensation stains the outer skins and causes dust to adhere which affects their appearance and hence quality. The standard method to avoid condensation on the skin is to heat the onions with large volumes of warm air for 7–10 days prior to removal from store. This method has a number of disadvantages.

(a) To avoid condensation of onions in store the temperature of the ventilating air must be raised slowly and be very carefully controlled. It may take a week to ten days to raise the onion temperature to the desired level.

(b) It is difficult in bulk stores with existing ventilation systems to warm up comparatively small quantities of onions to meet the day to day market requirements. Onions in excess of demand may therefore be warmed and begin to deteriorate some time before they are actually marketed.

(c) Onions which have been cold stored will sprout readily when their temperature has been raised. The shelf life of cold stored onions is therefore reduced by 7–10 days, the time required to heat the crop within the store.

This work was undertaken when both Bill Maunder and Chris Bishop were ADAS Mechanisation Advisers in Eastern Region. Chris Bishop is now a Senior Lecturer in Agricultural Engineering at Writtle Agricultural College. Bill Maunder is a Mechanisation Adviser with ADAS in Eastern Region.


Chris Bishop


Bill Maunder

It was therefore decided to carry out tests on the effect of short term high temperature heat on the outer surfaces of the bulbs so that the skin temperature would remain above the dew point of the packhouse during market preparation. This specification meant that radiant heating had to be used.

Equipment

After a number of laboratory tests and calculations, it was decided to carry out trials using portable propane fired gas heaters and roller table with wooden rollers. The specification of the equipment was as follows:

Heating Units

3 dual pack heaters, each with an output of 7.33 kW; Face area with shield 430 mm x 305 mm;

Face area of each heat surface 140 mm x 180 mm;

1 single pack heater with an output of 3.66 kW;

Face area with shield 270 mm x 305 mm;

Total heat available 25.6 kW;

Total area of radiant heat surface available including shields 0.48 m^2, without shields 0.17 m^2;

Length of heating surface over roller table 1.83 m;

Height of heating surface above roller table 203 mm;

Roller Table

Length 2.6 m;

Effective width 0.53 m;

Rollers constructed of timber;

Conveying speed 0.13 m/s, based on a single object taking 20 seconds to travel the length of the inspection table. At this conveying speed, an onion would be under the heating surface for 15 seconds. To determine the effect of extending the heating period in this work, the roller conveyor was momentarily stopped a number of times during a particular test run.

Test Procedure

Selected small batches of onions were allowed to pass over the roller table and under the heat source for periods of 15, 30 and 45 seconds. In a fourth test, a batch of onions which completely covered the roller conveyor passed under the heat source for a period of 45 seconds.

This latter approach was considered necessary to ascertain the effect of the heaters on a typical commercial presentation of onions which included some top and loose skins. The temperature of the outer skin was measured with fine thermocouple wire junction probes placed directly onto the onion surface, and coupled to a "Comark" electronic thermometer. The occurrence of condensation on the onions was assessed visually and recorded.

Results

All the work was carried out at an ambient temperature of 10°C and a relative humidity of 84%, giving a dew point of 8.6°C.

A summary of the results obtained in test runs 1–3 are given in tables 1–3. The fourth test run was carried out on a fully loaded roller conveyor which prevented the onions from rolling over as evenly as they had done in the previous runs to present all surfaces of the onions to the heaters. There was also a certain amount of trash present.

The throughput on the roller conveyor was approximately 4–5 tonne/hour. The initial temperature of the outer skin was 3°C, which increased to 10°C after treatment. Condensation occurred after five minutes on one or two onions, but after ten minutes no more onions were affected in this way. After fifteen minutes the situation was very similar, but after thirty minutes general but slight condensation had occurred on all bulbs. Undesirable side effects were not observed on any of the radiant heated onions.

Conclusions

The work showed that it was possible to raise the surface temperature of onions quickly and general condensation on the crop during market preparation could as a result be avoided. It is concluded that 45 seconds under the heat source can help to avoid condensation for up to one hour from removal from cold store by which time the onions will have been netted. It is likely that no condensation will occur after this time has elapsed as the whole onion will be approaching equilibrium with the ambient air in the packhouse.

The in-line radiant heating system, as well as removing the risk of condensation, also offers the following benefits:

(a) the process is continuous so that only those onions destined for the day's market are treated,

(b) as the traditional in store warming up period is no longer necessary when using in-line radiant heaters, shelf life is extended by 7–10 days or more,

(c) the technique helps to ensure that the quality of the onions in the cold store is retained to the point of sale.

Table 1 — Under heating surface for 15 seconds

Run	*1*	*2*	*3*	*4*
Initial temperature of surface	3.0	3.0	3.0	3.0
Temperature immediately after treatment	7.0	9.0	5.5	9.0
Temperature after 120 seconds	5.5	5.5	6.5	7.0
Temperature after 300 seconds	5.0	6.5	5.5	NR
Temperature after 600 seconds	5.0	6.0	NR	7.0
Temperature after 720 seconds	NR	NR	2.5	7.0
Temperature after 900 seconds	4.5	6.5	NR	NR
Temperature after 1200 seconds	3.0	NR	NR	NR
State in respect of condensation after 0.75 hours	slight	none	severe	none

All temperatures in °C
NR – not recorded on this sample

Table 2 — Under heating surface for 30 seconds

Run	*1*	*2**	*3*	*4*
Initial temperature of surface	3.0	2.0	2.5	3.5
Temperature immediately after treatment	15.0	8.0	15.0	16.0
Temperature after 180 seconds	9.5	6.5	8.5	10.0
Temperature after 300 seconds	9.0	5.0	8.5	8.5
Temperature after 600 seconds	7.0	4.5	7.5	8.0
Temperature after 900 seconds	7.0	3.5	7.0	8.0
State in respect to condensation after 0.75 hours	slight	severe	none	severe

All temperatures in °C
**Loose surface skins on onions*

Table 3 — Under heating surface for 45 seconds

Run	*1*	*2*	*3*	*4*
Initial temperature of surface				
Temperature immediately after treatment				
Temperature after 180 seconds	9.5	9.0	9.5	10.0
Temperature after 300 seconds	9.5	9.0	9.0	9.5
Temperature after 600 seconds	8.5	9.0	9.0	9.5
Temperature after 900 seconds	7.5	8.0	8.5	8.5
State in respect of condensation after 1.00 hour	none	none	none	none

Comment

In-line radiant heating of onions has been used commercially in some cold store and grading stations.

Development of a rotary soil shaper for raised beds

D MacIntyre

Introduction

AN alternative to growing vegetables in rows or ridges is to grow them in beds. Normally in ridge cultivation sufficient space is left between each row to accommodate the tractor wheels, whereas with beds consecutive rows of vegetables are sown in fairly close proximity over a width free from tractor wheelings. Crops grown on beds make better use of rainfall or irrigation than those grown on ridges because run off from beds is greatly reduced as shown by Prestt (1983). In wet conditions, raised beds keep the young plants above the water table and away from compacted soil caused by the passage of tractor tyres.

Normally, beds are worked and planted between the markings left by suitably spaced tractor wheels and, apart from the depressions left by tractor wheels, the vegetables can be said to be grown on the flat. Alternatively the surface level of the top of the bed can be raised well above the tractor wheelings. There is an interest in this latter method but there is no suitable commercial machinery for forming raised beds.

The Smallford through-shafted rotary ridger (fig 1), designed at the Scottish Institute of Agricultural Engineering, was modified as a bed shaper and a series of trials were undertaken to compare the growth and yield of various vegetables on flat beds with those sown on raised beds formed by the bed shaper.

Machine development and description

The rotary ridger was modified by replacing the central ridger unit of a three unit machine with a powered cylindrical levelling rotor (fig 2). From each of the two remaining outer rotors, the outside set of helical tines was removed to avoid interference with the adjacent bed previously formed. The function of the central rotor was to transfer soil thrown up by the outside rotors towards the centre of the machine and produce a raised bed with a level surface (fig 3). The soil movement was achieved by arranging one half forming a right handed skeletal auger while the other half had a left handed configuration. The even spreading of the soil across the bed was achieved by a combination of blade angling and spacing. A cage roller was mounted on the rear of the bed former to consolidate the top surface and crush small clods. Like the rotary ridger, the soil shaper was designed to work in previously tilled soil.

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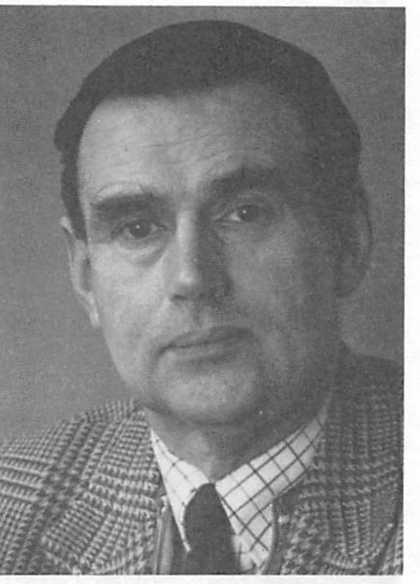

Field trials with vegetables

Trial procedure During 1982–4, flat beds were compared with raised beds as two methods for growing vegetables. A trial area of approx. 0.4 ha of sandy loam soil was heavily manured and ploughed in the autumn. A pH of 6.4 was maintained with lime application and an overall base fertiliser dressing of 625 kg/ha (20–14–14) was broadcast and incorporated with a Triple-K cultivator Secondary cultivation was carried out in the spring with a spiked rotary cultivator after which the beds were formed on 183 cm wheel centres. The raised beds had a flat top 132 cm wide and about 15 cm above the furrow bottom. The beds were

Fig 1 Through-shafted rotary ridger at work

Fig 2 Soil shaper conversion showing detail of cultivating and levelling rotor

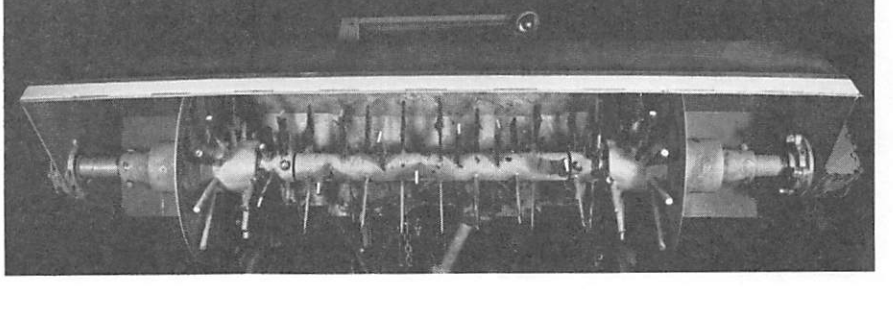

Fig 3 Soil shaper forming bed

Table 1 Difference in yield (%) between crops grown in flat and raised beds

	Crop yield differences, %					
Year	*Cabbage*	*Cauliflower*	*Leek*	*Carrot*	*Red beet*	*Swede*
1982	+12 (8.66)	NA	0 (3.01)	0 (4.87)	NA	+15 (5.22)
1983	-7 (7.81)	- 12 (0.88)	NA	+7 (3.10)	+33 (1.70)	NA
1984	NA	NA	NA	+9 (3.17)	0 (3.69)	NA
Mean	+ 2.5 (5.83)	- 12 (0.88)	0 (3.01)	+5 (2.20)	+16.5 (3.02)	+15 (5.22)

NA = Not sown in a particular year.
Numbers in brackets = Standard error between treatments.
NB Positive figures indicate an advantage for raised beds.

rolled with a flat roller prior to sowing.

A random layout of plots was used and treatments were replicated either three or four times depending on the site area. A stale seedbed system was used for weed control, the herbicide mixture used being Ramrod and Dackthal. For preventive control of cabbage root fly, carrot fly, flea beetle, etc, insecticide granules were incorporated in the soil with a Horstine Farmery applicator fitted to the seeder units.

In 1983, conditions at sowing were very wet, followed by a prolonged period of drought. In 1984, an even longer drought occurred which also coincided with brassica seedling emergence. Since no irrigation was available at the sites, yields were lower than expected from all treatments. Yields were estimated by hand harvesting and weighing 10 metre lengths of row.

Treatment results and discussion

The results are given in table 1 in the form of proportional differences between flat and raised beds. There is an apparent trend for root vegetables to give higher yields on raised beds than flat beds, whereas there is an indication of the converse results for leaf vegetables, however, the results were not statistically significant ($P < 0.05$). An added advantage of raised beds for root vegetables was the drier and less compact soil providing easier lifting conditions at harvest.

Other crops

(i) Potatoes

There has been a considerable increase of interest in growing potatoes in beds, although it rapidly declines after growers suffer the difficulties of harvesting beds in a wet autumn. Interest has come chiefly from growers on lighter irrigated soil who have been concerned about the loss of moisture from ridges due to evaporation and run-off. The use of beds results in a reduction of moisture loss from these sources, and by using a raised bed the difficulties mentioned previously with harvesting can, to some extent, be overcome. Manufacturers have developed machines for close three-row planting to suit bed-growing and have conducted demonstrations in association with the raised bed shaper.

Seedling trees

In forest nurseries, raised beds can be used with advantage in the first stage of sowing and growing trees as it enables the trees to be lifted mechanically with greater ease and with less root damage.

The Forestry Commission has successfully used the machine for a season at one of their nurseries.

Overseas

As a result of publicity, numerous overseas enquiries have been received regarding the use of the raised bed shaper to form various beds to suit locally grown crops such as sugar cane, tea, cotton and groundnuts. It is possible to modify the machine to produce the shape and height of bed by alternating the tine configuration of helical rotors.

References

Prestt A J (1983). Soil management and water — use of potatoes. PhD thesis (unpubl), Silsoe College.

The Agricultural Engineer

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The manuscript should be typewritten with double spacing and wide margins on one side of A4 paper. The original and one copy are required for editing and printing.

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There should be no stop at the end of any heading or caption unless the last word is an abbreviation of which the stop is a part.
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