HGCA

RESEARCH REVIEW No. 11

CHANGING STRAW DISPOSAL PRACTICES

DECEMBER 1988

Price £7.50

HGCA RESEARCH REVIEW NO. 11

CHANGING STRAW DISPOSAL PRACTICES

A review of ADAS/AFRC research seeking to identify advantages and disadvantages of straw incorporation, prepared by members of the ADAS/AFRC STRAW DISPOSAL OPERATIONS GROUP

R.D. Prew (Chairman)	IACR
B.D. Smith (Tech. Secretary)	IACR
J.H. Baldwin*	ADAS Cambridge
B.C. Ball	SCAE
D.G. Christian	IACR
G.W. Cussans	IACR
D.B. Davies	ADAS Cambridge
S.H.T. Harper	IACR
R.H. Jarvis	ADAS Boxworth EHF
A.E. Johnston	IACR
E.I. Lord	ADAS Wolverhampton
J.H. Orson	ADAS Cambridge
D.E. Patterson	IER
P.L. Redman	ADAS Silsoe

* Deceased 3 March 1988

CONTENTS

Chapter		Page
	Abstract	1
	Glossary of terms	2
1	Introduction	3 - 6
2	Machinery Implications	7 - 11
3	Straw Decomposition	12 - 14
4	Establishment and Early Growth	15 - 18
5	Yields	19 - 23
6	Crop Nutrition	24 - 28
7	Weeds	29 - 32
8	Pests	33 - 36
9	Diseases	37 - 40
10	Other Autumn-Sown Crops	41 - 43
11	Economics and Management of Systems	44 - 47
12	Summary & Conclusions	48 - 53
13	Recommendations for Future Work	54 - 56
	Acknowledgements	57
	Further Reading	58 - 61

HGCA RESEARCH REVIEW NO. 11

CHANGING STRAW DISPOSAL PRACTICES

A review by members of the
ADAS/AFRC Straw Disposal Operations Group
Edited by R.D. Prew and B.D. Smith
AFRC Institute of Arable Crops Research,
Harpenden, Herts. AL5 2JQ

ABSTRACT

An ADAS/AFRC Group, formed in 1984, has coordinated a joint research programme on alternative straw disposal methods. Results obtained to date from this collaborative research are summarised in this review.

The work has centred around field experiments on a range of soil types under different climatic conditions. It has concentrated on the mechanical feasibility, and the agronomic consequences, of incorporating straw into soil. With some limitations existing machinery appeared capable of achieving acceptable incorporation. Ploughing was generally the most successful method, although on heavy textured soils there have been problems of subsequently obtaining satisfactory seedbeds. Shallow non-plough systems were least suited to light textured soils but gave good results on heavier land provided that annual grass weeds did not become a major problem, in which case strategies for their control, like occasional ploughing, must be considered. Unacceptable increases in the incidence of pests and diseases have not yet occurred where straw has been incorporated regularly. Continued assessment on a number of sites will be required to follow long-term effects of straw incorporation on soil fauna and flora and also on the cycling of organic matter and nitrogen derived from it.

This review, completed in December 1988 and with 61 pages in the full article, was funded by the HOME-GROWN CEREALS AUTHORITY, Hamlyn House, Highgate Hill, London, N19 5PR, from whom copies may be obtained at a price of £7.50 each (postage and packing included).

GLOSSARY

ADAS	Agricultural Development and Adisory Service.
AFRC	Agricultural and Food Research Council.
Anaerobic	Absence of free oxygen.
BYDV	Barley Yellow Dwarf Virus.
Cellulose	Complex polysaccharide carbohydrate, a fundamental constituent of plant cell walls.
Hemicellulose	Carbohydrate related to cellulose, and a constituent of plant cell walls.
IACR	AFRC Institute of Arable Crops Research.
IER	AFRC Institute of Engineering Research.
Inoculum	Live particles of a micro-organism or virus availble for colonisation of a host.
Lignin	Complex polymer deposited in plant cell walls confering strength and rigidity.
Median length	The length at which there are equal numbers of straws of greater and smaller lengths.
Obligate pathogen	Disease causing organism capable of living only on a host.
Prophylactic	Preventative treatment applied as an insurance against disease.
SCAE	Scottish Centre of Agricultural Engineering.
Vector	Insect able to transmit a virus.

INTRODUCTION

R.D. Prew, IACR, Rothamsted

The increasing use of burning as a means of disposing of unwanted straw has been accompanied by increasing protests over the undesirable side effects of the practice including hazards from smoke, and damage to hedgerows and trees. In 1973 the National Farmers Union (N.F.U.) produced a report on the use and disposal of straw and proposals for a straw burning code-of-practice. In spite of this, the problems continued and reached a peak after the harvest in 1983 when weather conditions resulted in 'smuts' from the field being carried long distances provoking a more general public outcry. Following this a new N.F.U. code and statutory regulations were introduced to control straw burning. In addition ADAS/AFRC started a co-ordinated research programme on alternatives to burning. This programme is(?) aimed to identify the problems and consequent changes needed in agricultural practice should more rigorous control of straw burning be introduced.

The increase in area involved in changing totally to straw incorporation as the method of disposing of all unwanted straw can be seen from Table 1.

The figures underestimate the area burnt as they do not include areas of stubble burnt after baling; a not uncommon practice. Thus, if in 1984 burning had been banned there would have been at least an additional 1.25m ha of crop residues, mostly wheat, to be incorporated. The figures for 1987 show an increase in the area on which straw was incorporated but some of the increase was almost certainly due to the poor weather conditions which prevented burning, rather than a deliberate change in farming policy.

The change from burning to incorporation necessitates changes in primary and seedbed cultivation techniques. In the longer term it will lead to changes in the physical, chemical and biological conditions of the soil which could be expected to modify the need for fertilizer and pesticide applications. The effects of these changes fall into two categories; those directly attributable to the presence of straw and those of changes in cultivations needed for straw incorporation, but which occur irrespective of the presence of straw.

Table 1. Extent of different methods of straw disposal used in 1984 & 1987*

	1984 Straw			1987 Straw		
	baled	incorporated	burnt	baled	incorporated	burnt
Winter wheat						
'000 ha	638	184	1041	692	466	716
%	34%	10%	56%	37%	25%	38%
Winter barley						
'000 ha	732	33	152	676	73	132
%	80%	4%	16%	77%	8%	15%
Spring barley						
'000 ha	491	24	60	424	40	50
%	86%	4%	10%	83%	8%	9%

* MAFF Straw Survey. Sample of 2400 (1984) and 2035 (1987) farms grossed up to give estimates for England and Wales based on June census of area of crops grown.

This review reports results from the first four years of this co-ordinated research programme. The main topics covered are given by the chapter headings, and with the exception of the chapters 10 and 11 on "Other Autumn-Sown Crops" and "Economics and Management of Systems" refer to the incorporation of cereal straw for a following cereal crop; mostly wheat followed by wheat. The geographical locations of the experiments are shown in Fig. 1.

Fig. 1. Distribution of Experimental sites.

There was also 1 site at SCAE Edinburgh.

There was a wide range of soil types which, for the purpose of this review, have been grouped into 4 types as shown below:

Very Heavy:	Heavy clay soils. Impeded drainage likely. e.g. Denchworth series.
Moderately Heavy:	Clay soils where drainage problems are less likely. Often calcareous. e.g. Hanslope series.
Medium:	Medium loams, silty soils, sandy clay loams e.g. Beccles series.
Light:	Light loams, sandy and chalk soils. e.g. Newport series, Andover series.

A range of cultivation equipment was used but the results indicate that these can be considered under two main headings, defined for this review as:

Plough systems - where the straw and surface layer of soil are inverted, most often by a mouldboard plough (15-20cm).

Non-plough systems - where the straw and the surface layer of soil are mixed, most commonly by tined and disc implements (10-15cm).

On a few sites direct drilling or minimum tillage (5cm) was used, these systems are not included in the non-plough category.

MACHINERY IMPLICATIONS

P.L. Redman & T.J. Brassington, ADAS Silsoe

The main mechanisation aims of a straw incorporation system are to:

a. distribute crop residue below the soil surface
b. leave a firm seedbed free from material which will impede drilling
c. avoid additional operations or energy use.

The factors most likely to influence this are soil type, straw distribution particularly, long loose straw, and the cultivation equipment used. In plough systems, which are the most widely used, the presence of straw has proved less significant than the management of secondary cultivations to produce an acceptable seedbed.

Straw chopping

All straw choppers produce a range of chop lengths. Results of chop length analysis, using a technique developed by IER, showed that median length was the best figure in assessing chop length and this is the figure used in this review. Combine-mounted straw choppers have the advantage of working on 'fresh', dry straw. The majority perform satisfactorily, leaving straw with a median length of 5 cm or less. Field experience suggests that straw of this length causes few problems with any method of incorporation. Straw of 5 - 12 cm may be difficult to incorporate without some form of inversion, whilst material exceeding 12 cm can only be incorporated by ploughing.

Combine mounted choppers rarely affect the output of modern combines and the latest are easily disengaged. The performance of choppers of varying design differ little in relation to chop length, which is also little affected by straw throughput. The aggresssive action of some combine mechanisms, e.g. rotary combines, on the straw can increase amount of straw fragmentation.

Tractor-driven choppers involve an extra operation and have a high power requirement (20 kW/m width) but can be useful when it is necessary to change to incorporation when burning is prevented by prolonged wet weather.

Spreading straw and chaff

Straw choppers do not spread straw uniformly, particularly when working on combines with cutting widths in excess of 4.5 m. The resulting large amounts of straw and chaff in the centre of the cut are difficult to incorporate with shallow cultivation techniques and have been associated with poor growth of the following crop. Chaff spreaders have recently been introduced as attachments to combines, but as yet there is limited information on their performance.

Incorporation techniques

Plough system Ploughing to a depth of 15 - 20 cm is the most common system in spite of the high costs, mainly for labour and machinery requirements. It is favoured because on many soils it reduces the risk of problems with seedbed preparation and drilling, particularly in a wet autumn. However, on a heavy soil in dry conditions, creating a seedbed can be expensive, time consuming and relatively unsuccessful.

Ploughing buries straw effectively and is not sensitive to the chop length. Long stubbles of 17 - 23 cm are preferred to minimise the quantity of loose material and, where the previous crop has lodged, it can be beneficial to chop the laid straw using disc harrows. Cultivating prior to ploughing often causes problems in wet conditions. Whilst it is not necessary for the decomposition of straw, it can sometimes help in the control of volunteers and weeds. 'Skim' attachments are normally used as these give more complete burial of the straw but tend to leave it in 'pockets' through the profile. 'Trashboards' work best with loose surface soil and, when used without skims, spread the straw evenly through the profile. They leave some straw on the surface, but this is unlikely to cause serious problems. 'Trashboards' have a slightly lower (4%) draught than skims when working in comparable conditions but this is unlikely to be a major consideration.

On heavy land 30 cm wide bodies are preferred to aid tilth formation; on light land wider bodies are acceptable. Shallow ploughing to a depth of 15 cm will bury straw effectively but any subsequent cultivations must be shallower to prevent straw being brought to the surface. Shallow ploughing minimises power consumption and clod formation, although this still can be a problem when the land is wet and/or has been compacted by wheelings at harvest. Standard clearance ploughs are acceptable in all but extreme conditions when large amounts of wet straw are present.

Two new implements - the Mixaplough and the Sturplow - have been developed for straw incorporation. The Mixaplough, developed at IER, achieves good mixing down the profile but can leave an uneven surface in 'strong' soil conditions. SCAE developed the p.t.o powered Sturplow which also achieves good mixing although some straw remains on the surface; where the soil is reasonably friable, this machine produces a finer tilth in one pass than other implements. This often eliminates the need for further cultivations before drilling.

Non-plough system Combinations of tines and discs give higher work rates and are better suited to some soils than ploughing, but 2 or 3 passes are generally required to achieve acceptable incorporation. Ideally, cultivation is started immediately after harvest, working successively to depths of 5 cm and 10 - 15 cm. Optimum depth is probably 10 cm; shallower working has rarely been successful. Heavy discs are desirable to achieve penetration; the more aggressive twisted 'share' tines tend to result in both uneven mixing and uneven surface conditions.

Systems using a deep rotary cultivator to produce a coarse tilth are the most effective of the non-plough techniques. All non-plough systems require the stubble to be short and the straw chopped to less than 5 cm median length, as any longer material - particularly the root 'balls' - will tend to remain on the surface.

Recent studies indicate that the continuous use of shallow non-ploughing systems of incorporation may lead to benefits in increased resistance both to soil compaction and soil erosion particularly on weaker soils; work on this needs to be continued.

Costs, labour and power inputs

The relative labour use and costs of these two basic systems compared with burning are shown in Table 2.

Table 2. Relative labour use and costs of cultivation systems

	Man hours/ha		Cost £/ha	
	Light land	Heavy land	Light land	Heavy land
Burning with minimum cultivations	2.1	2.3	30	45
Incorporation				
tines/discs	2.4	2.9	40	60
plough	2.1	3.8	45	95

Power inputs range from 50 kW/ha for shallow non-ploughing techniques to 130 kW/ha for typical plough systems. Shallow ploughing, deep rotary cultivation, heavy twisted shares and the Sturplow require intermediate inputs of 90 kW/ha. The Mixaplough and the mouldboard plough have similar power requirements.

Consolidation

In many seasons there is a need to conserve soil moisture by consolidation. On heavy land, excessive drying results in the formation of clods which are difficult to break down into a seedbed. Consolidation using rolls, furrow presses or land packers can be effective in conserving moisture and producing tilth, but timing is critical. On heavy land the best effects are often obtained after a period of drying so that the soil is no longer plastic, but before strong clods are formed. Carefully timed consolidation by rolling has consistently resulted in small yield improvements in ADAS trials.

Light land can be consolidated immediately after primary cultivation. Furrow presses linked to the plough are effective for this purpose and by combining operations improve labour and machinery utilisation and also straw-soil contact, promoting straw breakdown. Measurements indicate that the design and weight of the furrow press does influence draught forces, but at 3-5 kW for a 4-furrow press these represent only 10-20% of the total power requirement for the ploughing operation.

Sowing the crop

Straw per se causes few, if any, problems with drilling following ploughing, provided consolidation has been effective in avoiding dry cloddy seedbeds. Where straw has been incorporated shallowly with discs and tines, the presence of long straw and stubble can result in problems with most seed drills in wet autumns. Wider coulter spacing of disc and tine drills is an advantage in these conditions. In drier seedbeds, Suffolk, disc or tine coulter drills all give good performance, and narrow spaced coulters can be used provided a straw chop length of 5 cm has been achieved.

Trials at SCAE have demonstrated that broadcasting is a better method of establishing winter cereals where reduced cultivation has left straw near the surface, but it is worth noting that broadcasting seed into dry soil delays emergence more than drilling.

STRAW DECOMPOSITION

S.H.T. Harper, IACR, Rothamsted

Straw decomposition is a biological process in which the soil microbial population uses the crop residue as a source of carbon and energy. The rate of straw decomposition is of most concern because it determines the duration of the early stages of decay when straw close to seeds or roots can inhibit crop establishment. Farmers are also worried when apparently undecomposed straw, ploughed down the previous season, is returned to the surface by autumn cultivations. However, field experiments have not shown any serious yield loss that could with certainty be attributed to the products of straw decomposition. Undecomposed straw only builds up in the long term where land is regularly direct drilled; here it accumulates on the surface.

Limits to decay rate

Straw consists primarily of cellulose (40%) and hemicelluloses (35%) organic compounds which are readily degraded by the soil microbial population. Lignin, although a relatively minor component (15%), is particularly important because it decays very slowly and forms a protective barrier around much of the cellulose and hemicelluloses. Any adverse effects of straw on crops are most likely to occur during the initial rapid decay of that fraction (20-25%) of cellulose and hemicelluloses NOT protected by lignin. The weight loss of straw recovered from the soil can be determined from the increase in the proportion of lignin present.

Decay of incorporated straw during autumn is limited primarily by temperature and moisture (the latter only for a brief period in dry years). In studies at SCAE straw near the soil surface experienced higher temperatures and decayed faster than straw buried more deeply by conventional ploughing. Although significant differences in decay rate were recorded for 3 soils of contrasting texture, they resulted primarily from differences in dates of incorporation rather than from soil type. A simple model of decay indicates that date of incorporation is a much more important determinant of decay than location or soil texture because earlier incorporation increases the number of days the soil remains above the temperature at which decomposition effectively stops.

In the experiments monitored to date, differences in weight loss were mostly confined to autumn and the amount remaining after 12 months was largely independent of method or date of incorporation. Although ploughing may return old straw to the surface, at least 65% of its original weight has been lost. Such decomposed straw retains little of its original strength and is normally shattered during seedbed preparation. It has little if any potential to damage the following crop.

There is no evidence that the straw of current, widely-grown varieties of winter cereals in the UK decays at significantly different rates. However, straws may differ physically. This can affect the performance of chopping machinery and subsequently influence the ease of incorporation.

Microbiology of decay

The identity of the active fungal populations present on straw throughout the year can vary between soils. However, major differences were found only during spring and summer when the protective action of lignin limits availability of the remaining straw. Lignin-degrading fungi (basidiomycetes) are major agents of decay at these times of the year. They have been isolated and their potential for decay demonstrated in the laboratory. Very little is known of the distribution of these organisms and whether or not they are absent from some arable soils.

Toxins

In very wet seedbeds there can be a lack of oxygen (anaerobic conditions) and in these circumstances toxins such as acetic acid may be produced from straw. Such conditions are less likely when soil is mixed with straw during incorporation. However, the mechanism by which seedling growth is retarded when incorporation leaves straw close to the surface remains to be explained. Greenhouse pot experiments have revealed that nitrogen availability may contribute to the effect, but other, as yet unidentified, mechanisms may also operate.

Accelerators

A lack of detailed knowledge of the mechanisms by which decomposing straw slows seedling development inhibits identification of the potential value of accelerators. The common assumption that faster decay can alleviate the adverse effects of straw remains to be substantiated.

Although it is known that chemical treatments, mostly alkaline, can aid straw decomposition they are not appropriate for large-scale application in the field. Decay can also be accelerated by a reduction in the size of straw but a chop length of less than 0.1 cm is necessary for any significant increase. This could not be achieved at acceptable cost in the field.

Microbial treatments are made on the assumption that some soils are deficient in the organisms necessary for decomposition. Field experiments with inoculants applied at incorporation have failed to show any response to the addition of cellulose-decomposing fungi, but lignin-decomposing Basidiomycetes caused much more rapid loss of weight during the following spring and summer. Experiments in progress will show whether quicker decomposition in the spring results in any significant amelioration of the adverse effects of shallowly incorporated straw on crop development at that time.

ESTABLISHMENT & EARLY GROWTH

D.G. Christian & E.T.G. Bacon, IACR, Rothamsted

Establishment and early growth can be affected by the presence of straw, this usually occurs when straw has been located close to the seedling. However, in good conditions for crop growth these early effects diminish with time so that the final crop yield is often unaffected or only marginally reduced. Unfortunately some of the effects on early growth may have been obscured by increases in the numbers of volunteers, particularly as shallow non-plough systems favour both.

Factors affecting establishment and early growth

Visual symptoms such as crop yellowing and poorer growth have been observed frequently during the winter and early spring. It is not clear to what extent, if any, these symptoms have been the result of toxic products from straw decomposition, a temporary limitation of nitrogen supply, seed bed conditions, or other as yet unidentified factors.

In dry autumns cultivations can lead to excessive moisture loss and the production of coarse dry seedbeds with inadequate fine crumb structure and poor consolidation. This can result in poor crop emergence and delayed tillering. Seedbeds of this type are most likely to occur on soils with a large clay content which have been ploughed rather than cultivated with tines or discs.

Non-plough methods leave more straw on the soil surface or buried shallowly where it can impede drilling. Seeds that are sown too shallowly may be eaten by birds, small mammals and slugs. In addition germinating plants may be poorly rooted into the soil, and killed in severe winters.

The presence of incorporated straw rarely affected germination or early growth when plougherd into the soil; but non-plough systems, particularly shallow ones, has decreased both germination and the amount of dry matter produced by April. Compensatory growth in late spring has usually made up for these early differences (Table 3).

Table 3. Plant population and dry weight of winter wheat as related to depth of cultivation and straw disposal on a clay and a silt loam soil.

Tillage method, cultivation depth and soil type	Straw burnt			Straw chopped		
	plants /m^2	shoot dry weight g/m^2		plants /m^2	shoot dry weight g/m^2	
	Nov	Apr	Jun	Nov	Apr	Jun
Clay						
Disc/tine 5 cm	250	200	1840	140	90	1900
Disc/tine 10 cm	220	150	2430	190	100	2090
Disc/tine 15 cm	280	180	2320	170	120	2150
Plough 20 cm	270	170	2480	250	160	2250
Plough 30 cm	270	150	2000	300	150	1880
Silt loam						
Disc/tine 15 cm	300	220	1870	250	110	1440
Plough 30 cm	280	210	1590	276	160	1740

Volunteer cereals

In recent years, particularly in those with dry autumns, volunteer cereal plants have been a problem. When present in large numbers they compete with the sown crop and their grain may reduce the merchantable quality of the crop if there is a change in cultivar or species. Volunteer populations were greatest with non-plough cultivation of chopped straw and least with ploughing and burning (Fig. 2).

Fig. 2. Effects of straw incorporation and cultivations on the incidence of volunteers.

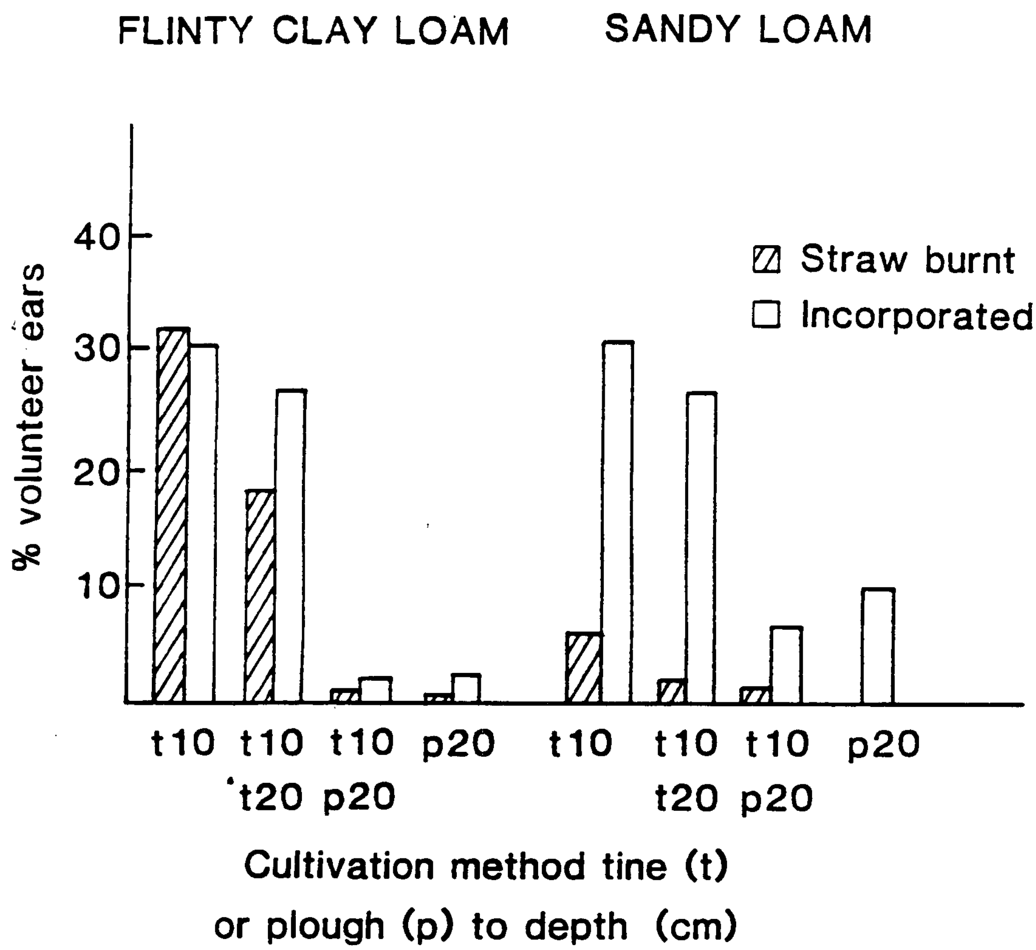


Table 4 shows the effect of cultivation method on a heavy clay soil in two consecutive years. In the first year, 1984/5, there were few volunteers but, in the second year only, ploughing to 15-25 cm controlled volunteers.

The results in 1984/5 also serve to illustrate that although tining to 5 or 15 cm reduced plant number compared to ploughing, this did not influence ear number at maturity. By harvest, the differences in early crop growth and development (Tables 3 and 4) had largely disappeared.

Table 4. The effect of method of straw incorporation on establishment and fertile ear number on a heavy clay soil in two years.

	Plough			Non-plough			Plough			Non-plough		
Depth cm	5	15	25	5	15	25	5	15	25	5	15	25
Year	1984/5						1985/6					
Establishment												
Plants $/m^{-2}$	325	360	370	255	350	420	1050	380	390	695	635	630
Maturity												
Ears $/m^{-2}$	550	500	565	505	570	510	800	505	555	755	690	715

Soil type and effects on establishment

On the heavier soils cloddy seedbeds following ploughing have been more common than after burning and shallow non-plough systems, both of which aid tilth formation. Experiments comparing such systems have not yet been running long enough to show whether in the long term the benefits in soil structure from increased levels of organic matter following straw incorporation can reverse this trend. Methods of cultivation have a less marked effect on lighter soils which, in any case, are normally ploughed and on which the benefits of increased organic matter have already been demonstrated.

YIELDS

E.I.Lord, ADAS, Wolverhampton

Straw incorporation may affect yields either directly (by physical or biological effects on growth), or indirectly (by affecting the incidence of weeds, pests or diseases). The change from burning to straw incorporation may also affect husbandry, in particular choice of cultivations, and this in itself may affect yields. Results for cereal followed by cereal are summarised here according to soil type (see Introduction) and season.

On light and medium soils ploughing has given higher yields than non-ploughing for straw incorporation, and effects on yield relative to burning and ploughing have been negligible. On the heaviest soils, differences in yield between plough and non-plough systems of incorporation have been small and there is scope for using whichever combination of cultivations gives the timeliest drilling on a given farm. The mean yield loss on changing from burning without ploughing to incorporating straw (whether by ploughing or disc/tine cultivations) was about 1% on heavy soils.

Effect of cultivation system on yield

The presence of straw encourages farmers to plough. However, on heavy soils, particularly in Eastern England, ploughing can result in dry, cloddy seedbeds with the risk of delayed drilling and poor establishment. The experiments reported here compared cultivation systems drilled on the same day, so that they cannot take into account effects on timeliness of drilling or farm workload.

Previous experiments showed that, where straw was burnt, disc/tine cultivations yielded about the same as ploughing on heavy land in most years, but yield depressions could occur after ploughing in dry autumns. On light soils ploughing gave better yields than non-ploughing. These results were confirmed in the recent experiments.

Where straw was incorporated on light soils, the plough system outyielded the non-plough system by an average of 7%. As the clay content of the soil increased, the advantage of ploughing decreased, and on the very heavy soils the two systems gave similar yields. (Table 5.A). After a dry autumn (1985-6) ploughing depressed yields on several sites on heavy and medium soils, due to the exceptionally delayed establishment in dry, cloddy seedbeds.

Effect of straw on yield: Ploughed land

Ploughing down straw has hardly ever affected crop establishment compared with ploughing after burning. Few differences in husbandry, pests or diseases have been reported. Yield effects have been correspondingly small on most experiments, with 24 of 52 showing a yield increase, and 22 a yield decrease relative to burning. There was no difference due to soil type (Table 5.B).

A few sites, particularly in 1986, showed large but unexplained yield depressions, which were in some cases related to poor growth in summer. It remains to be seen if this problem persists or is due to chance effects.

Effect of straw on yield: Non-ploughed land

Incorporation of straw without ploughing is not common practice at present, even on heavy soils. However, recent experiments show that on such soils it could be a viable option, particularly in combination with rotational ploughing (Table 5.C).

Germination and early growth can be adversely affected when straw is incorporated without ploughing. However, plant numbers have generally proved sufficient for compensation to occur, and yield losses have been smaller than at first feared, particularly on the heavier soils.

Of 62 experiments, 37 showed a yield loss relative to burning where straw was incorporated by discs and tines. The mean loss was less than 1% on the heaviest soils, rising to almost 10% on the lightest

Table 5. Effects of straw incorporation systems on yields

(Results of ADAS experiments 1983-87: no of experiments in brackets)

Harvest Year	SOIL TYPE: Very Heavy	Mod. Heavy	Medium	Light	Mean
A. STRAW INCORPORATED: CULTIVATION EFFECTS					
Yield of disc/tine as % of plough					
1983-5	103 (9)	96 (7)	96 (8)	93 (13)	96.5
1986	100 (5)	100 (5)	107 (4)	95 (4)	100.5
1987	97 (5)	99 (5)	88 (3)	89 (4)	94.0
Mean:	100.5	98.0	97.5	92.5	97.0
Best treatment:	Disc/tine	Plough	Plough	Plough	
B. PLOUGHED; EFFECT OF STRAW					
Yield of straw incorporated as % of burnt					
1983-5	103 (3)	100 (3)	96 (4)	102(13)	100.5
1986	98 (4)	98 (4)	100 (3)	96 (7)	97.5
1987	101 (3)	98 (2)	97 (3)	100 (3)	99.5
Mean:	100.5	99.0	97.5	100.0	99.5
Best treatment:	Incorp	Burn	Burn	Equal	
C. DISC/TINE CULTIVATIONS: EFFECT OF STRAW					
Yield of straw incorporated as % of burnt					
1983-5	101 (8)	98 (7)	98 (8)	96 (5)	98.5
1986	101 (5)	97 (5)	96 (3)	86 (6)	94.5
1987	95 (5)	101 (6)	101 (2)	91 (4)	96.5
Mean:	99.5	98.5	98.0	90.5	97.5
Best treatment:	Burn	Burn	Burn	Burn	
D. EFFECT OF CHANGE FROM BURN-DISC/TINE TO CHOP-PLOUGH					
Yield of Chop-Plough as % of Burn-Disc/tine (for sites where burn-disc/tine would be preferred only)					
1983-5	99 (8)	102 (8)	101 (8)	102 (4)	101.0
1986	97 (4)	97 (5)	89 (4)	95 (3)	94.5
1987	100 (3)	100 (3)	103 (2)	103 (2)	101.0
Mean:	98.5	100.0	98.0	100.0	99.0
Best treatment:	Burn-DT	Equal	Burn-DT	Equal	

soils. On the medium and light soils, 20 of 28 experiments showed a yield loss.

Reasons for yield depression identified on some sites included grass weed infestation (mainly brome), compaction due to use of discs in a wet autumn, and increased sensitivity to herbicide overdose where the crop had rooted shallowly into surface straw (1 site). However, in the majority of cases yield losses were small and no specific cause was identified.

Effect of changing from burn-disc/tine to chop-plough

The majority of farmers would choose to bury straw if they could not burn or bale it. Yield differences between burning followed by disc and tine cultivations and incorporation by ploughing were studied on those experiments where non-ploughing would have been preferred in the absence of straw.

After moist autumns (harvest years 1983-5, 1987) the average yield loss was less than 0.5% (39 experiments). In 1986 however, 16 of 18 sites showed a yield depression after ploughing down straw, with a mean of -3% on the heavy soils and -8.5% on the medium and light soils. These results were associated with cloddy seedbeds on heavier soils, and under-consolidation on light soils. Yield losses occurred throughout the country and on all soil types. One extreme site was omitted from this mean: ploughing of a chalky stony hilltop resulted in a puffy seedbed and delayed emergence. The oat crop suffered severe winter kill and a yield loss of 35%. On less stony parts of the field yield differences were less.

Over all the experiments (1983-7), the change from burning and non-ploughing to ploughing down straw gave a 1% yield loss (Table 5.D). This excludes effects of changed machinery and labour workloads on timeliness.

Effect of premixing straw before ploughing

Premixing straw, by one or more passes of a tine before ploughing, has been recommended by some advisers (e.g. in Germany). In this country the practice has had negligible effects on establishment, early growth, husbandry or yield, with no trend apparent between soil types or seasons.

Conversely, where a pre-plough cultivation is felt by the farmer to be useful (e.g. weed control), there are no indications against its use. A delay in ploughing in order to premix is undesirable on heavy land, because it can lead to a loss of traction under wet conditions.

Long-term effects

Several current experiments have been running for 5 years or more. So far there is no evidence for a trend in yield effects with years of incorporation (except in the few cases where grass weeds have developed on non-plough incorporation plots).

CROP NUTRITION

E.I.Lord, ADAS, Wolverhampton

The main nutritional effect of a change to straw incorporation involves nitrogen. The total straw from an 8 t/ha wheat crop contains about 65 kg potash, 13 kg phosphate and 35 kg nitrogen. Baling removes about 2/3 of this, although burning results in loss of most of the nitrogen, much of the P and K remains behind.

If straw is incorporated its initial decay causes temporary immobilisation of soil nitrate. Symptoms of nitrogen deficiency, and visual response to autumn nitrogen, are common, particularly where straw is near the soil surface. Effects of autumn nitrogen on yield are much less common. Any effects due to the method of straw disposal are small relative to the many other factors which influence nitrogen response.

No change in either rate or timing of fertiliser nitrogen is necessary when straw is incorporated. Early spring nitrogen may be advantageous for crops with poor tillering or growing in poor soil conditions, for whatever reason.

Autumn nitrogen: Visual responses

The initial phases of straw decay have the potential to immobilise up to 30-40 kg of soil nitrate. This is more than is available in most arable topsoils in autumn. Autumn-sown crops quite often show transient nitrogen deficiency symptoms, and visual response to autumn nitrogen fertiliser; these are most common where straw is incorporated without ploughing. Ploughing enhances mineralisation of organic nitrogen, and also places straw further away from the young seedling, so that more nitrogen is available in the 30-90 cm soil zone during the winter; thus deficiency symptoms are much less common (Table 6). When early growth has been retarded by the presence of straw, application of 40 kg/ha autumn nitrogen has usually increased dry matter production to levels similar to those on corresponding burnt plots without nitrogen (Table 7).

Table 6. Effects of straw disposal on mineral nitrogen in the soil

Site	Year of expt	Soil Depth	Straw burnt Disc/tine	Straw burnt Plough	Straw incorporated Disc/tine	Straw incorporated Plough
		cm	kg nitrogen/ha			
Rochford	1 (Nov)	0-20	72	-	51	56
Rochford	4 (Feb)	0-30	35	35	38	31
		30-90	152	182	111	157
Boxworth	4 (Dec)	0-30	12	-	10	15
		30-90	32	-	25	44

Table 7. Effects of autumn nitrogen on early growth

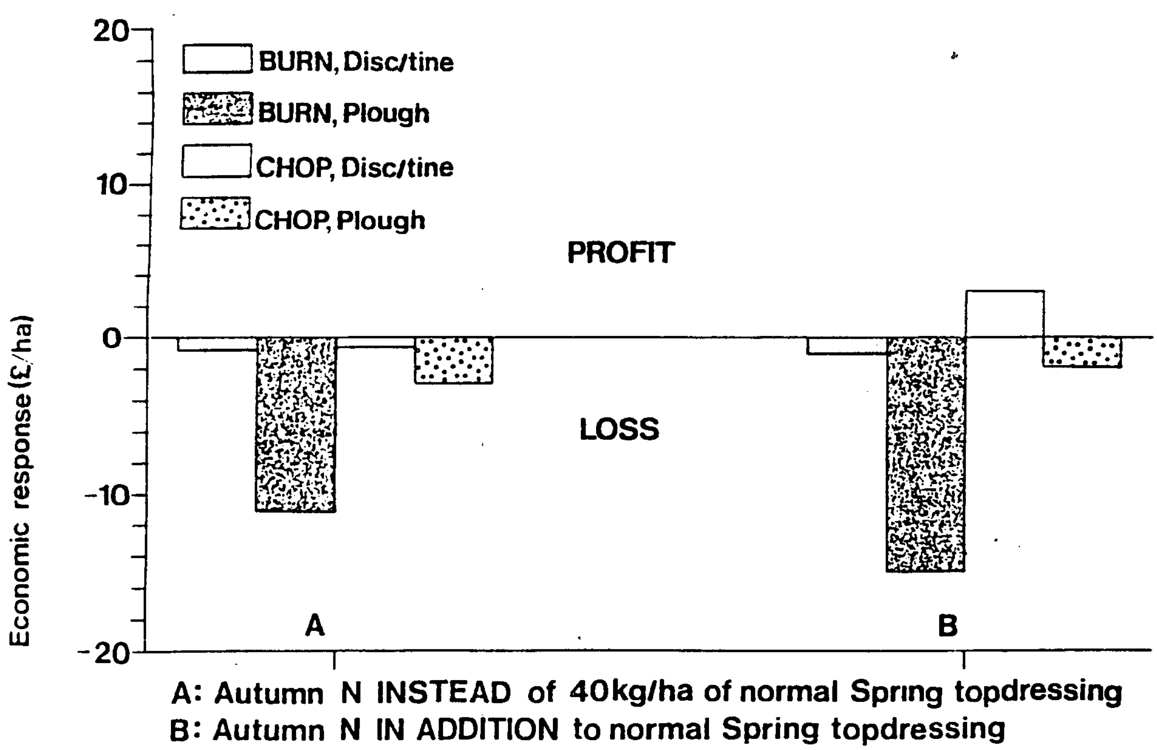
Site	Year of expt	Aut N	Straw burnt Disc/tine	Straw burnt Plough	Straw incorporated Disc/tine	Straw incorporated Plough
		kg	mg dry matter/plant			
Rochford	1 (Nov)	0	97	-	73	77
		40	115	-	86	84
Bovingdon	1 (Feb)	0	77	86	55	66
		40	105	-	90	106
Chishill	1 (Nov)	0	33	-	22	31
		40	42	-	33	34

A few experiments have tested mixing nitrogen with straw before incorporation. This has been less effective in promoting early growth than a topdressing after drilling.

Autumn nitrogen: Yield responses

It is well established that autumn nitrogen is not economic where straw is burnt, even though visual responses are quite common. In general differences in early growth of winter cereals, unless very large, have rarely resulted in differences in yield. The question is, does straw incorporation alter this picture? In 33 experiments, over several sites and a wide range of soil types, applying 40 kg/ha autumn nitrogen was unprofitable on average, for all methods of straw disposal, when compared with saving this nitrogen for the main spring topdressing (Fig 3 A). In a detailed experiment on a heavy soil, autumn nitrogen was only about half as effective as the same amount of nitrogen applied in spring, regardless of whether straw was burnt or ploughed down.

Fig. 3. Responses to Autumn Nitrogen
(Assuming N at £0.30/kg, grain at £100/t)



A larger group of experiments tested the effect of autumn nitrogen in ADDITION to the spring topdressing. When the spring topdressing was too low, the response to additional nitrogen could not be distinguished from a specific response to autumn N. There were small differences between straw disposal methods which were consistent with the differences in soil mineral nitrogen. However, the extra autumn N was uneconomic where straw was ploughed down or burnt, and barely paid for itself where straw was incorporated WITHOUT ploughing (Fig 3 B).

Early spring nitrogen

Nitrogen applied in autumn is at risk from loss by leaching or denitrification. Increasing the early spring topdressing (from 40 to 80 kg/ha) has therefore been considered where straw is incorporated. Responses have been evenly divided between positive and negative, with no consistent effect of straw disposal method. Useful responses have been seen in a few experiments, where crops were very backward and so increase in tillering could be advantageous. Some of these were on cloddy seedbeds after ploughing, and some after straw incorporation without ploughing. Conversely incorporating straw without ploughing often resulted in high plant populations, due to volunteers, so that an increase in tillering would not be advantageous. This may partly explain the lack of consistent benefit from early spring nitrogen.

Total amount of nitrogen

Because straw decay immobilises nitrate, and this nitrogen is released only slowly over succeeding years, an increase in the total requirement for nitrogen fertiliser might be expected with straw incorporation, at least in the early years. Some slight evidence for this has been found on a few experiments mainly in years 1-3 of incorporation. Of 21 comparisons, the yield response to extra nitrogen (above farm rate) was greater where straw was incorporated than on a corresponding burnt treatment in 11 cases, but was smaller in 5 and negative on both in 5. The mean response was not economic regardless of treatment (-0.03 t/ha where straw was burnt, +0.05 t/ha where straw was incorporated, whereas 0.12 t/ha was needed to pay for the extra nitrogen).

Evidence from these and more detailed experiments implies that differences in the optimum rate of nitrogen are very small. Significant differences in the optimum rate of nitrogen have been observed in a few trials, but not always in the expected direction, and often associated with confounding factors such as differences in maximum yield attained.

Long-term effects

Incorporation of straw will slowly increase the organic matter content, and the biological activity of the soil, both of which contribute to formation of good soil structure. Modelling at Rothamsted suggests organic matter % in the topsoil may increase by about 0.2 in the first 5 years, and continue to increase slowly for many decades. Changes of this size have been measured at SCAE, and improved workability is occasionally reported by farmers. The greatest benefits are expected in soils low in organic matter, but even then will be difficult to measure or assess in economic terms.

Straw incorporation also increases soil nitrogen reserves, both directly due to the nitrogen content of straw, and indirectly by immobilising up to 40 kg/ha nitrate which might otherwise be lost by overwinter leaching or denitrification. The effect on leaching will be particularly important on light soils with high nitrate residues. Mineralisation of the organic nitrogen over succeeding years would be expected to reduce the requirement for fertiliser nitrogen. However, this process will be slow; even after 4 years of straw incorporation the soil mineral nitrogen concentrations in the topsoil have still generally been lower where straw has been incorporated than where it has been burnt (Table 6). The Rothamsted model suggests that if 5 t/ha of straw is incorporated each year 35 kg/ha of nitrogen will be mineralised in the 15th year and subsequently.

WEEDS

G.W. Cussans & S.R. Moss, IACR, Long Ashton

The period when straw disposal takes place - between maturation of one crop and establishment of the next - coincides with an important phase for weed populations. Many seeds are produced, which may be shed before harvest, removed with the grain or remain in the field with the straw and chaff. Only those seeds which survive this phase (often a small minority) can become weeds. Straw disposal and cultivation systems can have a major influence on weed survival. Annual grass weeds and volunteer cereals, which are among the most important in cereal production systems, are considered.

Straw burning is only one element in a complex of factors. Weeds are influenced by crop rotation, time of planting and many other husbandry factors in addition, of course, to the efficacy of herbicides applied. Table 8 gives an example of the practical effects and interactions of straw disposal and tillage which have been recorded on black-grass populations (in the absence of herbicides).

Table 8. Black-grass plants per m^2 in autumn 1986

Straw disposal	BURN	CHOP	BALE	CHOP
Primary cultivation	TINE	PLOUGH	TINE	TINE
	135	165	640	800

The effects of straw burning

Survival of weed seeds Very high temperatures may be generated, up to 700^{o} C at ground level, beneath a thick swath of burning straw. Many seeds are killed, the percentate mortality depending on the temperature attained and the time for which it is maintained. Data are available for wild-oats, black-grass, barren brome, cleavers and volunteer cereals. The kill by burning has ranged from 30 to 95% depending on species and heat generated. Brome and black-grass appear to be more vulnerable than wild-oats.

In addition to killing seeds, burning may affect the behaviour of those which survive the burn. Dormancy may be lost in a proportion of the seeds, resulting in more rapid germination. This may be beneficial where such seedlings can be destroyed before sowing the next crop. However, with early sown crops, breaking seed dormancy may increase the numbers of early emerging weeds. These are the most competitive.

Effects of straw residues on herbicide activity The carbon in burnt straw residues is highly adsorptive to herbicides, and can substantially reduce herbicide performance if such residues are retained close to the soil surface. Straw itself is much less adsorptive, although it may form a physical barrier and prevent herbicides reaching the soil. Table 9 gives some typical data from field studies which have shown major reductions in performance of some herbicides where burnt straw residues were present near the surface in direct drilling or shallow cultivation systems. Much smaller reductions have occurred where unburnt straw was on the surface and no adverse effects have been recorded where straw has been incorporated by ploughing.

Table 9. % control of ryegrass by chlortoluron

Straw disposal Primary cultivation	BALE PLOUGH	CHOP PLOUGH	CHOP TINE/DISC	BURN DIR.DRILL
	88	86	58	48

The effects of tillage

Pre-mixing prior to ploughing Shallow cultivation soon after harvest was widely practised with the objectives of disrupting the rhizome system of perennial weeds and stimulating seeds of annual species to germinate before ploughing. This practice declined with improved herbicides for control of perennials but has been revived to some extent with the different objectives of accelerating decomposition of chopped straw and improving the quality of the final burial by ploughing. Limited evidence suggests that the practice has very little beneficial effect on populations of most annual weeds or on the rate of decomposition of straw. Some seeds are stimulated to germinate but the loss of seeds from the soil is less than would occur anyway by mortality, which is greatest on the soil surface. Only with volunteer cereals and barren brome was there an overall beneficial effect: even with these species, the effects of pre-mixing are dependent on there being sufficient soil moisture to permit germination and this cannot be guaranteed. Also if the soil gets too wet following pre-mixing, ploughing becomes difficult or impossible.

Plough vs non-plough systems Soil inversion by mouldboard ploughing has a major effect on weeds. Some can be characterised as "long cycle" weed species notably knotgrass, charlock and poppy. Seeds of these species have marked dormancy and great longevity (up to 50 or 60 years). Such long cycle species appear to be well adapted to surviving when soils are ploughed.

In marked contrast, the grass weeds and a few broad-leaved species, notably cleavers, are "short cycle" species. They produce seeds with relatively weak dormancy and comparatively short life span. Burial of freshly shed seeds by ploughing prevents these short cycle plants from exploiting their great seed producing capacity to the full because seeds rarely germinate at depth and, if they do, few seedlings survive. When the land is reploughed and seeds are brought back towards the surface, short cycle species cannot benefit if insufficient seeds remain viable.

Non-plough systems are extremely vulnerable to cleavers, volunteer cereals and the annual grasses, notably black-grass and the brome grasses. Good herbicides are available for black-grass, but their performance is barely good enough to prevent an increase in population in a rotation dominated by cereals. The brome grasses are less widespread in occurrence but are very strongly favoured by non-plough systems and there are no herbicides available which give adequate control. Volunteer cereals, unlike the other weeds, may have a major effect on grain quality even when gross yield is relatively little affected.

The weeds most strongly favoured by minimum tillage non-burning systems are the "short cycle" species. Population models and some practical experience suggest that ploughing on a rotational basis every four or five years would be needed to prevent an excessive increase in weed populations.

PESTS

B.D. Smith, IACR, Long Ashton

Slugs which are capable of causing severe damage and crop failure are the most important pest favoured by straw incorporation. However, during the four years of this trials programme, none of the experimental sites (Fig 1) have suffered serious slug damage except crops at Letcombe which were direct drilled. No major changes to levels of crop damage by other pests have occurred so far, although some changes in the incidence of other pests and soil fauna have been recorded.

Slugs

Detailed monitoring of total slug populations in the soil has been done on only a few sites. On one of these (Northfield Farm, Nr. Letcombe) populations reached 297/m^2 where straw had been incorporated for 6 years compared with 4/m^2 where straw had been regularly burnt. Lack of food and shelter following burning may be more important than direct mortality caused by heat. Minimum tillage with tines to depths of 5 or 10 cm had little effect on numbers, whereas ploughing to 5, 15 or 25 cm reduced numbers considerably. Although the proportional reduction after ploughing was greater with straw residues than with burning the total numbers were still higher after ploughing in straw than after burning. Whilst the numbers of all three species found at Northfield increased in the presence of straw residues, the hedgehog slug (*Arion intermedius*) increased more than the field slug (*Deroceras reticulatum*) or the silver slug (*Arion silvaticus*).

Larger slug populations do not inevitably lead to increased crop damage. At Northfield the degree of slug damage varied from year to year and did not closely follow slug numbers (Table 10). In autumn 1982 when maximum populations were 150-180 per m^2 wet conditions favoured activity and damage, but in 1984 when populations reached 300 per m^2 in a dry autumn, damage was less.

Table 10. Slug damage to winter wheat: effects of straw disposal and cultivation depth

Percentage of seeds and seedlings killed by slugs

Sowing Date	Burnt			Chopped		
	0 cm	10-15 cm	25 cm	0 cm	10-15 cm	25 cm
1982	6(7)*	-	-	47(133)	-	-
1983	6(5)	5(3)	-	36(77)	14(52)	-
1984	0(12)	1(8)	1(8)	26(140)	7(34)	4(36)
1985	1(81)	0(6)	1(2)	14(120)	1(30)	1(10)
1986	0(7)	0(0)	0(0)	1(14)	0(8)	1(6)

*Figures in ( ) are numbers of slugs/m^2, estimated from the mean on two sampling dates, just before and just after sowing.

The chemicals presently available for slug control (methiocarb and metaldehyde) have a limited effectiveness; a 50% kill is exceptional, and both can be damaging to non-target fauna.

Currently farmers have to assess damage risk from bait-trapping which is often unreliable, particularly in the presence of straw. Unless forecasting is improved, the present trend of annual increases in molluscicide use is likely to continue, and possibly accelerate as more farmers incorporate straw. However, blanket use of these molluscicides would be hard to justify given their limited effectiveness and their damaging effects on non-target fauna.

Aphids and Barley Yellow Dwarf Virus

Straw incorporation increases the incidence of cereal volunteers and grass weeds which can act as hosts for BYDV and its aphid vectors, thus providing a larger reservoir of virus infection for cereal crops.

Also prophylactic application of molluscicides is commonly used where straw is incorporated; these chemicals decrease some natural enemies of the cereal aphids that transmit BYDV.

The method of primary cultivation can also affect the incidence of the virus. In experiments at Long Ashton there was less BYDV associated with uncultivated (direct drilled) plots compared with plots which were ploughed. Thus an autumn spray to control the aphids would have been needed with ploughing but not with direct drilling. This may be a consequence of habitat disturbance by ploughing affecting the mortality or activity of aphid natural enemies. Therefore, if farmers incorporate straw by ploughing, and the next cereal is drilled early, there could be greater need for an autumn insecticide treatment.

There has been little work on the effect of straw treatment on populations of cereal aphids during summer but in one experiment at Rothamsted, numbers of 2 species were significantly greater on ploughed plots than on unploughed plots, again an effect which could be related to differences in natural enemy populations.

Other pests

Experiments at Rothamsted have consistently shown that the percentage of plants attacked by the stem borer (*Opomyza florum*) was greater with ploughing (burnt 41%, straw incorporated 40%) than with non-plough treatments (burnt 29%, straw incorporated 8%), and with non-plough incorporation damage was least, possibly because the increased surface litter reduced egg laying.

Soil fauna

Large changes in soil fauna in response to changes in cultural practice may take several years, as in the case of slugs. Monitoring of long-term straw disposal trials is being done in collaboration with the Institute of Terrestrial Ecology, to detect population changes of a range of species in food chains leading to birds. Early results show that many components of the soil fauna are often favoured by straw residues compared with burning. However, the change from a non-inversion to a plough system will decrease populations of some species (eg. earthworms and carabid beetles).

DISEASES

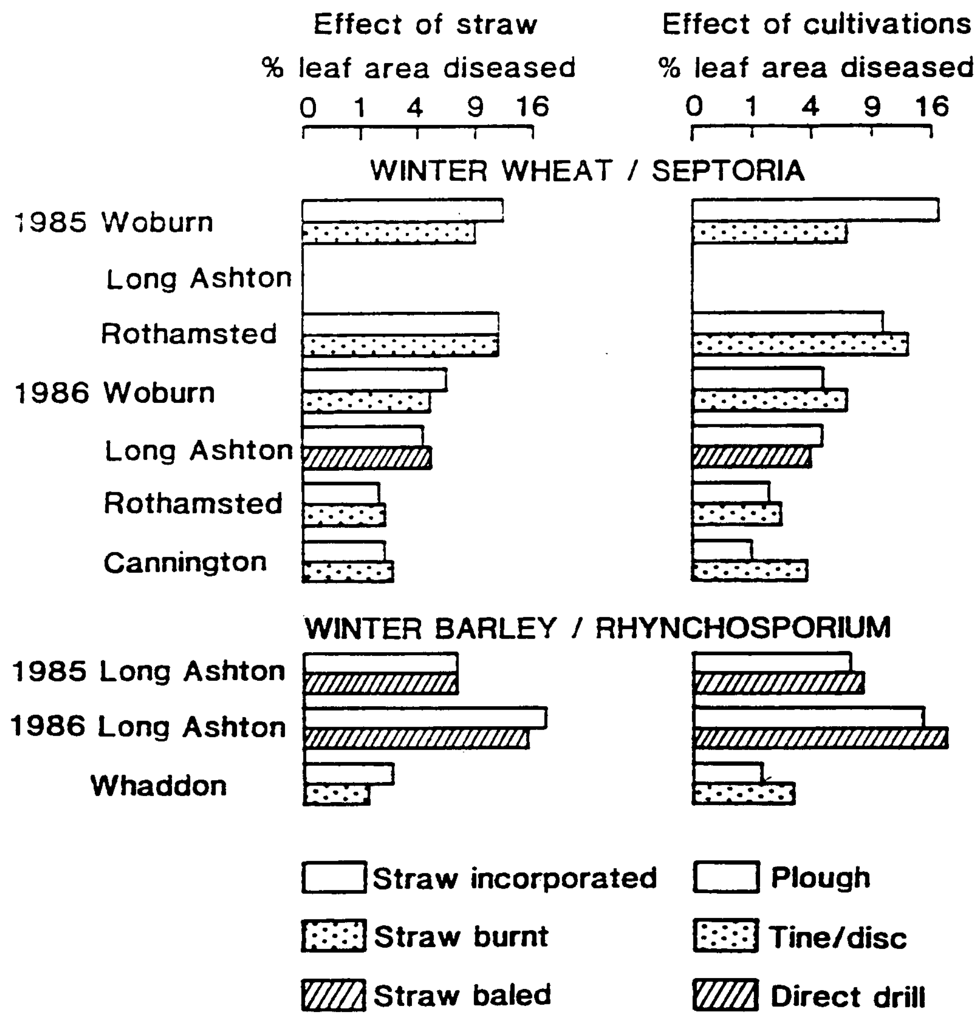
R.D. Prew, IACR, Rothamsted

The incorporation of straw may affect the incidence of cereal diseases by changing the survival and distribution of inoculum or by altering the crop growth and infection conditions. These can be slow and complex processes, particularly for soil-borne diseases, so the first four years of incorporation covered by this report can only be considered as the 'change over' phase.

Foliar diseases. The incidence of diseases caused by obligate pathogens (e.g. rusts and mildew) has not usually been much affected by straw residues. Trash-borne diseases (e.g. septoria on wheat, rhynchosporium and net blotch on barley) have sometimes been increased initially by straw incorporation methods that leave much trash on the surface, presumably because of increased amounts of inoculum, but effects have not been as large as might have been predicted from experiments in which straw, applied to a 'clean site' was the only source of inoculum. In some cases this increased incidence has persisted into the spring. However, where the growth of crops following burning was much better than that of crops after straw incorporation; then by summer the early differences in growth had disappeared. The effect of cultivation method has frequently had more effect on the incidence of these diseases than the effect of straw (Fig.4). However, in virtually all cases standard fungicide treatments have given equally good control whatever method of straw disposal has been used.

Cephalosporium leaf stripe has become very common on one site where it was greatly increased by shallow straw incorporation systems and particularly by direct drilling. On other sites only very occasional infection of plants has been recorded. Therefore, although further monitoring is needed, it appears that cephalosporium may cause only occasional crop damage. This would accord with the present status of the disease in wheat following leys where it is most common but nevertheless occurs only sporadically.

Fig. 4. Effects of straw incorporation and cultivation on the incidence of foliar diseases.



Stem base diseases. Eyespot has tended to be less severe where straw is incorporated than where it is burnt. This may seem surprising since burning must decrease the numbers of infected stem bases that remain to act as sources of primary inoculum. The explanation is uncertain but earlier results from direct drilling trials suggest that spore production is decreased in the presence of trash probably because of competition from other, faster-growing fungi. Sharp eyespot is less common but has sometimes responded similarly to the presence of straw residues.

Brown foot rot caused by *Fusarium* spp. has been more prevalent in non-plough systems. So far in most experiments the infection has been slight and would not be expected to cause serious yield loss. More monitoring of this disease is needed especially in areas where it commonly causes crop damage, e.g. Scotland.

Root diseases. Effects of cultivation method on the incidence of take-all have occurred independently of the presence of straw residues. In some cases these effects have been large. An example is shown in Table 11; on this site burning followed by shallow tillage had been used over a period of years apparently concentrating the take-all inoculum near the surface and so ploughing this down dramatically decreased disease incidence. More usually the effects of cultivation have been smaller, with shallow cultivation resulting in greater infection in the top 10 cm. during the winter and early spring. Thereafter this difference diminished although on some sites there was still more take-all at maturity following shallow cultivation.

Table 11. The effects of straw residues and cultivation methods on the incidence of take-all on winter barley at Whaddon in 1986.

Cultivation	Tined/rotary cultivated 15 cm.		Ploughed 20 cm.	
Straw	Burnt	Chopped	Burnt	Chopped
Take-all (% plants infected)				
November	71	73	22	22
April	72	83	36	47
June	99 (25)*	99 (29)*	91 (13)*	89(3)*

* ( ) % plants severely infected

The effects of straw residues on take-all have been inconsistent but on some sites the disease has increased where straw has been incorporated by shallow tillage. This could result from problems in achieving sufficient seedbed consolidation, lack of consolidation is known to favour the spread of take-all. The experiments have not yet run long enough to study the longer-term build-up and decline of take-all in soils where straw incorporation is well established. Pythium root rot has also been monitored but has shown no response to straw incorporation or cultivation method.

Other diseases. A husbandry change as major as straw incorporation will, over a period of some years, change the physical, chemical and biological characteristics of the soil to such an extent that diseases at present considered unimportant may become damaging. Cephalosporium and others could still emerge as important problems and thus continued monitoring of a limited number of sites is needed.

OTHER AUTUMN-SOWN CROPS

R.H. Jarvis, ADAS, Boxworth EHF

The establishment of winter oilseed rape without burning the straw of the previous cereal crop poses several problems mostly related to difficulties in producing a suitable seedbed; the main factors involved are weather and soil type. The time available for primary cultivations is also a factor and this in turn depends on whether the previous crop was winter barley or winter wheat; problems being more likely in the shorter interval after wheat.

When winter field beans follow a cereal the interval between harvest and sowing is normally of the order of eight weeks, so few problems would be expected with straw incorporation.

Winter oilseed rape after winter barley

It is normally possible to plough or employ some other fairly deep cultivation for straw incorporation after winter barley on light and medium soils with an acceptable chance of success. On the silty clay loam at Rothamsted in 1985-86, when a very dry autumn was followed by a long, cold winter, the success of incorporation depended on sowing date. Yields after either chopping the straw and incorporating it by tine cultivation, or baling the straw and tining the stubble, were similar to those following burning where the crop was sown on 22 August, but where sowing was delayed to 9 September, yields were considerably reduced by incorporating either chopped straw or stubble. In the following year, under more favourable conditions, incorporating straw or stubble did not reduce the yield compared with burning.

On the heavier chalky boulder clay at Boxworth incorporation has proved more difficult. Straw incorporation by ploughing or tine cultivation in autumn 1985 gave such low over-wintered plant populations that the plots were not taken to harvest. In 1986-87 autumn and winter conditions were more favourable and straw incorporation by tine cultivation gave satisfactory plant populations and yields similar to those after straw burning. However, in the wet autumn of 1987, none of the cultivation treatments involving straw incorporation gave adequate plant populations.

Winter oilseed rape after winter wheat

After winter wheat, straw incorporation by ploughing or tine cultivation in preparation for rape has proved difficult and except on the more favourable soils the chance of success is slight. On two ADAS sites, a shallow chalk loam and a fine silt, these methods gave satisfactory results in the favourable season of 1986-87. However, on two chalky boulder clay sites in 1985-86 and one clay site in 1986-87, yields were reduced where straw was incorporated. Because of the problems of seedbed preparation on the heavier soils following ploughing or traditional tine cultivation, methods of establishment requiring little or no soil disturbance need to be considered. In particular, rape seed can be broadcast into the wheat crop just before harvest; subsequently the straw is chopped on the combine, followed by either very shallow cultivation with a rotary harrow and then rolling, or no cultivation at all. Alternatively, the straw can be left in the swathe to be baled and removed as soon as possible.

When tested at Boxworth in the dry autumn of 1985, these methods gave reasonable crop establishment but growth was very slow and losses during the winter were severe. In the much more favourable season of 1986-87, they all gave good establishment and yields at Boxworth, and at Rothamsted, broadcasting into the wheat followed by straw chopping and particularly by baling, with no soil disturbance in either case, were successful. Light cultivation after straw chopping was tested at Boxworth and was also successful. In the very wet autumn of 1987, this was the only minimum disturbance treatment to give an adequate plant population at Boxworth. These broadcasting systems need further testing to establish their reliability over a range of seasons. Until they prove themselves there remains no consistently satisfactory method of incorporating straw for winter oilseed rape on the heavier soils.

Winter field beans

Results at present are confined to a single trial at Boxworth in 1986-87. Comparisons were made between straw burnt and straw chopped followed by either drilling after tined cultivation to 15 cm. or broadcasting the seed and then ploughing to the same depth. All treatments gave satisfactory crop establishment and there was no yield reduction where straw had been incorporated. Again, further tests are needed to check the reliability of these systems, but initially it seems that problems are unlikely.

ECONOMICS AND MANAGEMENT OF SYSTEMS

J.H. Orson, ADAS, Cambridge

A change from straw burning involves the heavy land farmer in both direct and indirect cost increases. The largest increase in costs is when the system changes from straw burning and minimal tillage to ploughing without straw burning. In contrast, the light land farmer may reduce costs by changing from ploughing after straw burning to ploughing after straw chopping. This section does not take into account the effect on yield of differing straw disposal systems. Any long-term benefits of crop nutrition due to straw incorporation rather than burning are also not allowed for.

During the autumn/winter 1985, ADAS carried out a series of case studies on 27 farms which had just adopted straw incorporation on a very significant proportion of the cereal area. The following comments are based on that study. The farms were contacted again in April 1988 in order to monitor their progress, particularly after the wet autumn of 1987.

Main conclusions of the 1985 study

Machinery stock For approximately 10 years after 1973, cereal profitability allowed significant investment in land drainage and machinery. This resulted in land being generally well drained and machinery complements often being sufficient to take on the extra operations required for straw incorporation.

Plough system On light soils, straw incorporation meant little or no change to cultivation practices and hence costs. Extra machinery requirements were often restricted to the purchase of a straw chopper. The cost of such a purchase may be partly or wholly offset by the time saved on straw burning. Some light land farmers bought cultivators for surface tillage prior to ploughing but trials have indicated that such purchases may not have been necessary.

On moderately heavy soils, straw incorporation meant a return to the plough. There was often sufficient tractor power to take on this extra work and purchases were restricted to ploughs, cultivators and straw choppers. Trials have indicated that the purchase of specialist cultivators may have been unnecessary. Extra capital and repair costs in 1985 averaged around £25/ha/annum and varied between £0-£38/ha/annum. A proportion of these costs should be offset by cheaper weed control, say £10-£25/ha/annum. The figures on machinery expenditure could be misleading because if farmers continued burning and with minimal tillage, there were potential savings to be made from decreased machinery costs.

Non-plough system Very few farmers are carrying out straw incorporation using non-ploughing techniques. This could be an acceptable alternative to the plough on the very heavy clays and silts where there is least enthusiasm for straw incorporation. Very little extra machinery costs would be involved. The success of the method will depend on good long-term weed control, particularly for barren brome but as yet this is not available. Even with a full spectrum of herbicides successful weed control may involve extra costs compared with minimal tillage with straw burning.

Management and labour There are unquantifiable practical advantages to straw incorporation. One of the most significant in the eyes of the farmer is avoiding the straw burning operation. The statutory requirement for more than one person to be present can severely reduce the flexibility to undertake other operations on the farm. In addition, ploughing in of straw can be carried out on every day of the week and in a wider range of weather conditions than straw burning.

There are also unquantifiable practical disadvantages to straw incorporation. The level of management will have to be higher on the heavy and very heavy soils. This is because of the likely need to return to the plough on the moderately heavy soils and the need for a very high standard of weed control where straw is incorporated by non-ploughing techniques on the very heavy soils.

Drilling time The 1985 study indicated that on the farms involved drilling was not delayed. However, delays in drilling could occur for two reasons. Firstly, it is more difficult to plough and to prepare a seedbed when heavy soils are dry. Secondly, ploughing and seedbed preparation are more time consuming than non-ploughing techniques. This latter factor could become more significant if the economics of cereal production result in machinery complements being cut below present levels. Any significant delay in drilling as a result of straw incorporation will almost certainly result in an additional yield loss.

Costings There are dangers in preparing any costings to compare systems which involve burning or not burning straw because of the number and complexity of quantifiable and unquantifiable factors. In 1986, ADAS mechanisation advisers estimated costs for the operations involved in straw disposal and the calculations in Table 12 are based on their findings, including the costs of labour, depreciation, fuel, repairs and miscellaneous costs.

Against the increase in costs involved in ploughing heavy land compared with non-ploughing must be set a decrease in herbicide costs of approximately £10-£25/ha. There may be increased herbicide costs where straw is incorporated by non-ploughing techniques when compared with non-ploughing with straw burning. In the absence of an effective brome herbicide in cereals, the system of non-ploughing without straw burning may not be possible.

These estimated costs may provide a more realistic comparison than the results of the 1985 case studies, where machinery complements were usually sufficient, with few additional purchases, to take on the extra

Table 12. Costings for straw disposal and cultivations on two soil types.

LIGHT LAND

Straw burning	£/ha	Ploughing down straw	£/ha
Straw clearance*	1.6	Chop straw+	0.7
Straw burning	2.4	Plough/press	38.0
Plough/press	38.0	Harrow	5.5
Harrow	5.5		
Total	47.5	Total	44.2

HEAVY LAND

Non-plough				Plough	
Straw burning	£/ha	Straw incorporation	£/ha	Straw incorporation	£/ha
Straw clearance	1.6	Straw chop	0.7	Straw chop	0.7
Plough headland	6.3	Disc/tine x2	34.0	Plough	58.0
Straw burning	2.4	Power harrow	23.2	Land packer	13.0
Incorporate ash	11.5	Roll	4.1	Power harrow	23.2
Seedbed cult.	11.5			Roll	4.1
Total	33.3	Total	62.0	Total	99.0

*straw clearance from fire breaks, +combine mounted straw chopper.

work involved with straw incorporation. Also it should be remembered that the case studies were done on farms that had already decided to change to a straw incorporation system, so presumably it was expected that the extra work was feasible. On other farms it may well be that fitting straw incorporation into the farm management programme will prove a much more difficult process.

SUMMARY & CONCLUSIONS

A co-ordinated ADAS/AFRC research programme was started in autumn 1983 to identify the problems and consequent changes in agricultural practice needed for the adoption of straw incorporation systems. The study was based on 38 field experiment sites covering most of the major arable areas of England together with 27 case studies on farms. The group involved has worked closely together and built-up considerable expertise which has been fully used in this review. This summary gives a brief outline of the major findings using the main section headings and with the exception of "other autumn sown crops" deals with results of winter cereals, mainly wheat, following another cereal crop.

MACHINERY IMPLICATIONS

* The machinery presently available is capable of incorporating straw satisfactorily. Ploughing to 15+ cm or non-plough cultivations to 10+ cm are capable of giving good results on most soil types.

* Power requirement for straw incorporation is greater than with burning and a minimal cultivation system.

* Chop length and spread of straw from current combine mounted choppers, although somewhat variable, are adequate. Even distribution is more important for non-plough incorporation and the use of chaff spreaders on combines with very wide cutterbars may be desirable.

* Seedbed tilth and consolidation have proved to be the major difficulties in cultivations for straw incorporation.

* Two new machines, the Sturplow and the Mixaplow were developed by SCAE and IER respectively and have shown promising results.

STRAW DECOMPOSITION

* There has been no long-term build-up of undecomposed straw. After 1 year straw may still be visible but is at least 65% decomposed and poses no problem.

* The rate of breakdown is adequate. Early incorporation increases the rate of breakdown in the autumn.

* There is no clear evidence of a need to enhance decay by chemical or microbial additives.

ESTABLISHMENT AND EARLY GROWTH

* Establishment is not seriously limited by the presence of straw incorporated to a depth of at least 10 cm, although with shallow non-plough systems the presence of volunteers can lead to an excessive plant stand.

* Visual symptoms of yellowing and poor growth can occur during winter and early spring with non-plough incorporation. Compensating growth mostly overcomes this.

* On soils where the change in cultivation system has resulted in a poor seedbed, establishment has sometimes been adversely affected. This has most often occurred with ploughing on heavy soils.

YIELDS

* On a few sites grass weeds have caused significant yield losses with non-plough incorporation.

* On light and medium soils ploughing was best; some yield losses occurred with non-plough systems.

* On heavier soils, straw presence had little effect on yield; difficulties in seedbed preparation caused some yield loss after ploughing, particularly in dry autumns.

* There may be additional losses if the change in system results in delayed drilling.

NUTRITION

* There is usually sufficient nitrogen in the soil in autumn for plant growth and straw decomposition. Additional nitrogen has sometimes given improved early growth but no consistent yield benefit, and should be avoided for environmental reasons.

* Additional spring nitrogen is not required, but on very backward crops applying part of the dressing earlier has been beneficial. In the long term less spring nitrogen may be needed because of a larger mineralisation of organic nitrogen.

* Incorporation of straw can help reduce leaching of nitrate during the winter.

WEEDS

* Weeds are probably the most common limit to the viability of non-plough systems. Severe infestation by annual grass weeds, particularly brome, has occurred on some sites with non-plough systems, suggesting the need for rotational ploughing within such systems.

* Volunteer populations were also increased with shallow incorporation resulting in problems of grain quality when changing variety or cereal species.

* Herbicides are adsorbed much less on to straw than on to burnt straw residues, and therefore have the potential to perform better. However, a high proportion of soil cover by straw may prove a physical barrier to soil-acting herbicides.

PESTS

* Slug populations were increased by straw but there was no clear evidence on the consequences of this for increased crop damage.

* Stem borers, particularly Opomyza, were less in the presence of surface trash.

* Soil fauna generally increased with non-plough incorporation compared to ploughing or burning the straw.

* There was no direct effect of straw incorporation on barley yellow dwarf virus. However, increases in volunteers, in molluscicide use and the amount of ploughing may all contribute to an increased population of aphid vectors in the future.

DISEASES

* With a standard fungicide spray programme there have been no yield differences. In the absence of fungicides trash-borne foliar diseases have sometimes been increased by the presence of surface straw.

* Non-plough incorporation has tended to decrease the incidence of eyespot but increase that of take-all, compared to ploughing or burning the straw; in most cases these effects have been small.

* One site had greatly increased amounts of cephalosporium where straw was incorporated shallowly.

OTHER AUTUMN-SOWN CROPS

* Oilseed rape: Where time and soil type allow preparation of a seedbed, a plough system is satisfactory; where this is not possible there is no consistently satisfactory method at present.

* Winter beans: Initial results show no problems with either plough or non-plough systems of incorporating straw.

ECONOMICS & MANAGEMENT OF SYSTEMS

* Where ploughing was already being used there will be no increased costs, and some saving in time.

* On heavy land where burning and minimal cultivations were previously used, changing to non-plough incorporation could increase costs by £10-£30/ha; changing to a plough system could increase cultivation costs by £40-£70/ha but could save up to £20/ha on herbicides.

* A high standard of management will generally be required for a successful incorporation system particularly on the heavier soils. If this is not forthcoming yields are likely to be adversely affected.

* Financial penalties will occur if yields are depressed by the change to straw incorporation.

* Fitting straw incorporation into the whole farm management system will pose differing but very real problems for some farmers.

This summary has highlighted the major effects experienced in the 4 years of the straw incorporation programme. Changes in the soil environment will continue with increasing years of incorporation. Thus there may well be further changes in soil workability, nutrient status and populations of weeds, pests, diseases and other wildlife. It is hoped that the programme will continue on a limited number of sites to monitor such effects.

RECOMMENDATIONS FOR FUTURE WORK

As mentioned in several sections of the review, the four years of work has looked at the mechanical feasibility of incorporating straw on a range of soils and the major initial effects on the husbandry, growth and yields. However, because of the long term nature of changes in the soil environment, it is very important that studies on a limited number of sites should be continued. This need, together with some more specialised proposals for future work is dealt with below:-

LONG TERM STUDIES ON CONTINUOUS SITES

* Comparison of nitrogen retention and release between burning and straw incorporation systems.

* Measure changes in organic matter content and type, soil structure, and workability.

* Measure changes in populations of weeds, diseases, pests and soil fauna, particularly for increased prevalence of species presently unimportant.

* Monitor the build-up and decline of take-all as modified by straw incorporation.

* Introduce rotational ploughing into a shallow non-inversion treatment on some sites for weed control.

* Monitor establishment, growth and yield in relation to the above items.

SPECIALIST PROPOSALS

Machinery

* Evaluation of new equipment and techniques, particularly chaff spreading.

* Work on seedbed preparation and consolidation on heavier soils and also consolidation on very thin and light soils.

* Continued development of equipment with inversion characteristics with higher workrates and contributing more to seedbed preparation, particularly single pass incorporation and secondary cultivation implements.

Straw decomposition

* Improve methods of assessing fungal activity and rates of straw decay.

* Follow up findings on the importance of lignin degrading Basidiomycete fungi in straw decomposition.

Establishment and early growth

* Investigate mechanism of retardation of seedling and winter growth.

Weeds

* Population studies on annual grass weeds and volunteers and their dormancy and survival patterns.

* Efficacy of herbicides in the presence of fresh and decomposing straw.

Pests

* Understanding the relationship between slug populations and damage in presence of straw and improved forecasting.

* Improve integrated pest management to limit need for insecticides and molluscicides with straw incorporation systems.

Other autumn-sown crops

* Further investigation of alternative methods of establishing oilseed rape in the presence of straw.

* Complete initial study on establishment of beans.

Economics of systems

* Obtain data on economics and management problems from a wider range of farms.

ACKNOWLEDGEMENTS

The group acknowledge with gratitude the major contribution to its work made by the late John Baldwin (ADAS). His wealth of experience in cereal agronomy and his personal qualities were invaluable.

The group also wish to thank the many members of ADAS and AFRC who have contributed in some or all stages of the programme, in particular the initial leadership of Dr. P.B. Tinker (AFRC, now NERC) who was charged with the responsibility for setting up the group.

Finally, we thank the Home-Grown Cereals Authority for commissioning this Review.

FURTHER READING

GENERAL ARTICLES

Cereal Crop Manual. C.D. Farman, P.J. Warry, M.R. Saul, P.V. Biscoe, D. Jansen (1987). Pub. Arable Unit RASE, 138p.

Cereal Pests and Diseases. R. Gair, J.E.F. Jenkins, E. Lester (1983). Pub. Farming Press Ltd., 259p.

Straw as a fuel for heating greenhouses. ADAS booklet 2386.

Straw as a feeding stuff. ADAS leaflet p. 551.

Straw disposal. ADAS leaflet p. 2419.

Straw, Soils and Science. Ed. J. Hardcastle (1985). Pub. AFRC, 28p.

Sraw Disposal and Utilisation. Ed. D.J. White (1984). Pub. MAFF.

Straw for the future - a discussion document. M.C. Hemsley (1982). Pub. Council for the Protection of Rural England, London.

Straw as an energy source. Ed. P.B. Tinker (1988). Pub. Commission of the European Communities. EUR 11256 EN.

The Straw Manual: a practical guide to cost effective straw utilisation and disposal. Bill Butterworth (1985). Pub. E. & F.N. Spore, 212p.

RESEARCH PUBLICATIONS

Machinery implications

A new rotary tillage implement for incorporating straw and other materials into the soil. M.J. Sharp, D. McIntyre, J.A. Pascal, B.D. Soane (1988). Proc. 11th Conference International Soil Tillage Research Organisation, July 1988, Edinburgh, p. 517-522.

Cultivation systems for straw incorporation on clay soils. E.T. Chittey et al. 1983-4 AFRC IER DN 1313. 1984-5 AFRC IER DN 1318. 1985-6 AFRC IER DN 1450.

Reduced tillage and straw incorporation for winter barley. B.C. Ball. D.C. Bickerton. E.A.G. Robinson (1988). Proc. 11th Conference International Soil Tillage Research Organisation. July 1988, Edinburgh. p. 565-570.

The Role of the Plough. T.J. Brassington (1987). The Agriculture Engineer Vol. 42 No. 2. Summer.

The performance of some different stubble cutting and straw chopping machines. C.R. Tuck et al. 1985 AFRC IER DN 1306.

Tillage and straw incorporation. B.C. Ball (1986). Soil and Water 14. 8-10.

Straw decomposition

Colonisation and decomposition of straw by fungi. S.H.T. Harper. J.M. Lynch (1985). Transactions of the British Mycological Society. 85. 655-661.

Microbial decomposition of cereal straw in arable soils. S.H.T. Harper. R.M. Bowen (1988). Aspects of Applied Biology 17. part 2. Environmental aspects of applied biology.

The chemical components and decomposition of wheat straw leaves. internodes and nodes. S.H.T. Harper. J.M. Lynch (1981). Journal of the Science of Food and Agriculture 32. 1057-1062.

The role of water-soluble components in phytotoxicity from decomposing straw. Plant and Soil. 65. 11-17.

Varietal and fertilizer effects on straw phytotoxins. S.H.T. Harper. F.B. Ellis. J.M. Lynch (1986). Biology and Fertility of Soils, 2, 109-112.

Establishment, growth and yield

A comparison of tine cultivation and ploughing with two methods of straw disposal on the growth, nutrient uptake and yield of winter wheat grown on a clay soil. D.G. Christian. E.T.G. Bacon (1988). Soil Use and Management 42. 51-57.

Effects of straw residues on the establishment, growth and yield of autumn-sown cereals. J.P. Graham, F.B. Ellis, D.G. Christian, R.Q. Cannell (1986). Journal of Agricultural Engineering Research 33, 39-49.

Straw incorporation by different tillage systems and the effect on growth and yield of winter oats. D.G. Christian, D.P. Miller (1986). Soil and Tillage Research 8, 239-252.

Straw residue management for autumn sown cereals grown on a clay soil 1979-87. D.G. Christian, E.T.G. Bacon, J.F. Jenkyn, D.M. Glen, R.J. Gutteridge (1988). Proceedings 11th Conference International Soil Tillage Research Organisation, July 1988, Edinburgh, p.607-612.

Crop nutrition

Straw incorporation, what about nitrogen? A.E. Johnston, D.S. Powlson (1988). Soil and Water 13, 12-13.

Weeds

A study of the population dynamics of <u>Avena fatua</u> L. as influenced by straw burning, seed shedding and cultivations. B.J. Wilson, G.W. Cussans (1975). Weed Research 15, 249-258.

Some effects of burning cereal straw on seed viability, seedling establishment and control of <u>Alopecurus myosuroides</u> Huds. Weed Research 20, 271-276.

Straw disposal techniques and their influence on weeds and weed control. G.W. Cussans, S.R. Moss and B.J. Wilson (1987). Proceedings 1987 British Crop Protection Conference - Weeds, 97-106.

The influence of cultural practices on the activity of soil-activating herbicides. S.R. Moss (1984). BCPC Monograph No. 27. Symposium on soils and crop protection chemicals, 77-86.

Pests

Cultivation, straw disposal and barley yellow dwarf virus infection in winter cereals. D.A. Kendall, B.D. Smith, N.E. Chinn, C.W. Wiltshire (1986). Proceedings 1986 British Crop Protection Conference - Pests and Diseases, 981-987.

Effects of straw disposal on slug problems in cereals. D.M. Glen, C.W. Wiltshire, N.F. Milsom (1988). Aspects of Applied Biology 17, Environmental aspects of applied biology 2, 173-180.

Estimating slug populations from bait-trap catches. D.M. Glen, C.W. Wiltshire (1986). Proceedings 1986 British Crop Protection Conference-Pests and Diseases 3, 1151-1158.

Diseases

Effects of straw incorporation and cultivation on cereal diseases. J.F. Jenkyn, R.J. Gutteridge, M.R. Thomas (1988). Aspects of Applied Biology 17, Environmental aspects of applied biology 2, 131-139.