CONTRACT REPORT
NO. 93/21
CARROTS: DISPOSAL OF STRAW USED FOR FIELD STORAGE
(FV92)

FINAL REPORT

03ECT630.SRR

ADAS

Final Report 1993 (Year 3)

Project No. FV92

Project Title: Carrots: disposal of straw used for field storage

Project Leader: Sally R Runham
ADAS Arthur Rickwood Research Centre
Tel: 0354 692531

Collaborating Partner: Richard E Cope
Silsoe Research Institute
Wrest Park
Silsoe
Bedford
MK45 4HS
Tel: 0525 860000

Project Co-ordinator: Dr Andrew Prestt

Date Project Commenced: March 1991

Date Completion Due: November 1993

Keywords: Carrots
Storage
Field Storage
Parsnips
Straw
Incorporation
Disposal

ADAS - FOOD, FARMING LAND & LEISURE

Report to: Horticultural Development Council
18 Lavant Street
Petersfield
Hants
GU32 3EW

ADAS Contract Manager: Dr M C Heath

Period of investigation: March 1991 to November 1993

No. of Pages: 60

No. of Copies: 7 (3 held by ADAS, 1 held by SRI)

Principal workers and authors of report: Sally R Runham, BSc (Hons, Hort), ADAS
Richard E Cope, Research Engineer and Cultivations Specialist, Silsoe Research Institute

Authentication: M C Heath

DR M C HEATH

INDEX

PRACTICAL SECTION FOR GROWERS

The aims of this two-year project were to find cost-effective methods of incorporating straw after field storage of carrots (or parsnips). It also aimed to provide a better understanding of the implications for agronomy of the next crop.

Six crops were established after incorporating straw (16 to 40 t/ha): five on mineral soils and one on peaty soil. Trials were established either in 1992 or 1993, following drier and wetter than average winters respectively. The straw had been incorporated using many different types of cultivations to determine the most cost-effective tillage systems. Each crop was given a range of nitrogen treatments. In some cases, part of the nitrogen was applied to the straw before ploughing it down. The following is a resumé of results from the project:

a. A questionnaire to growers, before starting the experiment, revealed that many different methods of cultivation were used requiring up to 9 passes. No grower chopped straw at that time (see page 51 for further details).

b. The cultivation strategy in this project focused on chopping the straw prior to mixing it with the soil, then ploughing. It was clear that if the straw was to be chopped properly it must be processed prior to removal from the storage bed otherwise it can become trampled and mixed with soil. For this, a new design of machine is required: a prototype is now being developed, initiated by this project.

c. Where the straw was chopped a much reduced number of pre-mixing cultivations sufficed prior to ploughing compared with the standard system where unchopped straw is cultivated using many passes of discs or tines, saving over £50 per hectare.

d. The 'minimal-mixed' straw could be ploughed down using a modified mouldboard plough with 99 cm (39") point-to-point and 69 cm (27") underbeam clearance. Growers could consider using a plough with 1.12m (44") point-to-point, and clearance of 76 cm (30"), fitted with large wrap-around skim tops with or without trashboards. This could invert the chopped residue without pre-mixing.

e. Incorporation of 40 t/ha of straw hindered subsequent crop development and reduced uniformity of crop stands. A yield reduction from straw incorporation occurred only in 1992 for linseed after carrots with 40 t/ha straw incorporated. There were no yield reductions on the other five sites, three of which had much lower quantities of straw.

f. Crop development was not hindered where straw was incorporated very uniformly, and yield was not compromised where extra nitrogen was applied to offset that used in the straw degradation process. The relationship between straw incorporation, crop development and response to nitrogen is complex and not fully understood. Growers may need to seek advice.

g. There appeared to be no benefits from applying part of the nitrogen requirement to the straw before inversion to assist in its breakdown. The nitrogen should be applied to the crop according to normal husbandry standards.

SUMMARY

In 1991, a questionnaire was sent to carrot growers to determine their approach to the incorporation of straw. The aim was to find out how this project could help to answer questions of agronomy, particularly nitrogen fertiliser use, and whether a more strategic approach to cultivations could be adopted (refer to page 51).

The effects of incorporating up to 40 t/ha of straw (which had been used for the field storage of vegetables) were investigated. Different degrees of straw and soil pre-mixing were examined in relation to subsequent plough and crop performance. The interactions between these variables and the rate and timing of nitrogen application were also investigated.

Results from the 1992 and 1993 seasons showed that additional pre-mixing cultivations, beyond those required for complete inversion by the plough, had no advantage in terms of crop performance. In straw which had been spread and partially chopped, two to three pre-mixing passes, each followed by pressing (1 t/m^2), were found to be sufficient for the successful operation of a mouldboard plough fitted with straight trashboards and having 39" (99.0 cm) point to point and 27" (68.6 cm) underbeam clearances. Between 90 and 190 kWh/ha were needed for effective pre-mixing operations. A prototype disc-type plough required less pre-mixing (40-130 kWh/ha) and a commercial "square plough" required more pre-mixing (220 kWh/ha) than the conventional plough for effective operation. In unchopped straw, between one and four additional passes were needed for effective operation of the ploughs.

In 1992, where straw was incorporated compared with being removed, the yield of linseed was reduced ($p<0.05$) from 1.8 to 1.3 t/ha when meaned over all nitrogen rates. However, at nitrogen application rates of 100, 130 and 160 kg/ha, yield of linseed increased ($p<0.05$) from 1.2 to 1.5 to 1.8 t/ha indicating that the peak of the nitrogen response curve had not been reached. With spring wheat and summer cabbage, similar trends were apparent but only the effects of nitrogen application rate were significant. Applying nitrogen to the straw before incorporation was of no benefit.

In 1993, three crops were established after incorporation of straw. There were two crops of linseed following the incorporation of 20 t/ha and 40 t/ha of straw respectively, and a crop of parsnips following incorporation of 20 t/ha of straw. Early linseed crop development was hindered by the incorporation of 40 t/ha of straw. However, yields of linseed and parsnips were not affected by the presence of the straw. The yields of all crops were similar whether there were many or few pre-mixing cultivations of the straw prior to ploughing. All crops responded to high

levels of nitrogen on the sandy loam soils (initially at indices 0). The presence of straw or number of cultivations did not affect the response.

The introduction of an effective straw chopping system would appear to be the most cost-effective means of reducing the pre-cultivation inputs required for a successful mouldboard ploughing operation. Further confirmation of this was provided in spring 1993 when the plough brought up large wads of long wet straw which had been pushed down into the soil by wheels at harvest time and also straw in the bed wheelways which premixing cultivations had not mixed into the surface profile. Chopping the straw after it had been removed off the beds was not effective in overcoming this problem because much of the straw remained inaccessible to the chopper.

Ensuring the straw is chopped before it is removed off the beds is seen to be the most practical approach to the problem and a machine for doing this, both in the presence and absence of a polythene sheet, is being developed.

The effects of incorporating straw that is chopped completely on subsequent crop growth and nitrogen requirement requires further evaluation.

OBJECTIVES

a. To develop a more strategic approach to straw incorporation cultivations following field storage of carrots and parsnips in order to minimise additional operations and costs.

b. To evaluate the effects of straw incorporation on the nitrogen requirement of the following crops.

INTRODUCTION

Growers field store at least one third of their main crop carrots to ensure that there is a continuity of supply during winter. The greater proportion, some 3,000 ha, is stored on mineral soil types which, unlike deep peat soil, offer little insulation from frost. This means that a very thick layer of straw is required if the roots are to be adequately protected and most growers now use, on average, 40 Hesston bales/acre or 40 t/ha (Appendix I).

At the end of the storage period, there is a problem with disposing of the straw. The aim is to ensure that the land can be returned to agricultural use within a few weeks of the carrot harvest. The cheapest method of disposal is to burn the straw, which is still legal, but currently less than half of the area is disposed of in this way. A standard mouldboard plough can mix the straw/ash remnants and reliably create a seedbed suitable for a small seeded crop such as linseed. However, burning of wet straw in spring is very difficult and can cause serious nuisance to neighbours. Additionally, all burning is subject to the requirements of the Clean Air Act 1968 (creation of dark smoke), the Highways Act 1980 as amended in 1986 (distance from roads), the Environmental Protection Act 1990 (nuisance) and the Health and Safety at Work etc. Act 1974 (worker safety). Growers, therefore, often chose to dispose of the straw by incorporation.

Incorporation of at least 40 t/ha of straw is expensive, whether done by growers or contractors. At present, growers mainly use repeated passes of large diameter heavy disc harrows, although a number of other implements are also used. The large wads of only partially-chopped straw may be effectively ploughed down out of sight, but if this straw is not in good contact with the soil it may not degrade adequately. Lumps of straw could subsequently be ploughed out again in the following autumn when preparing the land for the next crop.

The effects of straw incorporation after carrot field storage were tested in 1992 on three soil types; sandy loam, silt loam and loamy peat with following crops of linseed, spring wheat and summer cabbage respectively.

After harvest of these crops, the two mineral soil sites were monitored during their second season after straw incorporation.

In 1993, three further experiments were started, all on sandy loam soil. These comprised two crops of field-stored parsnips followed by either linseed or parsnips, and field-stored carrots followed by linseed. This report describes all experiments.

OUTLINE OF MATERIALS AND METHODS

Sites The schedule of experiments is shown in Table 1

Table 1: Schedule of experiments on sites from 1991 to 1993

Site	Soil	1991	1992	1993
1	Sandy loam 2%	Carrots (40 t/ha straw)	Linseed	Set-aside
2	Silty clay loam (3% OM)	Carrots (37 t/ha straw)	Spring wheat	Combining peas
3	Loamy peat (35% OM)	Bare soil (16 t/ha straw)	Summer cabbage	-
4	Sandy loam (2.8% OM)	-	Parsnips (20 t/ha straw)	Parsnips
5	Sandy loam (1.3% OM)	-	Parsnips (20 t/ha straw)	Linseed
6	Sandy loam (1.2% OM)	-	Carrots (40 t/ha straw)	Linseed

Treatments

a) Nitrogen application rate and timing (Table 2).

b) Cultivation sequences - see Tables 3, 9, 15 and 16 in Results section.

Table 2 Nitrogen rate (kg/ha) and application timing.

		To straw before ploughing	To crop at drilling/ planting	To crop as top dressing	Total
1992					
Site 1 (linseed)	a)	-	100	-	100
Index 0	b)	-	130	-	130
	c)	-	160	-	160
	d)	30	100	-	130
	e)	60	100	-	160
Site 2 (wheat)	a)	-	100	-	100
Index 0	b)	-	150	-	150
	c)	-	190	-	190
	d)	50	100	-	150
	e)	90	100	-	190
Site 3 (cabbage)	a)	-	-	-	0
Index 1	b)	-	100	100	200
	c)	100	100	-	200
	d)	100	200	100	400
1993					
Site 4 (parsnips)	a)	-	0	-	0
Index 0	b)	-	60	-	60
	c)	-	120	-	120
	d)	-	180	-	180
	e)	-	240	-	240
Site 5 (linseed)	a)	-	0	-	0
Index 0	b)	-	60	-	60
	c)	-	120	-	120
	d)	-	180	-	180
	e)	-	240	-	240
Site 6 (linseed)	a)	-	0	-	0
Index 0	b)	-	60	-	60
	c)	-	120	-	120
	d)	-	180	-	180
	e)	-	240	-	240

Husbandry

1992

Site 1: The straw was incorporated using a range of cultivation treatments (see Results section - Table 3) from 4-11 February 1992 and the linseed drilled on 12 April. The crop was given standard commercial inputs except nitrogen and harvested on 8 September 1992.

Site 2: The straw was incorporated using a range of cultivation treatments (see Results section - Table 9) from 20 February 1992 and the spring wheat drilled on 1 May. The crop was given standard commercial inputs except nitrogen and harvested on 1 September 1992.

Site 3: The straw was incorporated on 6 May 1992. The cabbage (sown in the glasshouse on 13 April) was planted on 11 May at 30 x 40 cm spacing. The crop was given standard commercial inputs except nitrogen and harvested on 27 July 1992.

1993

Site 4: The straw was incorporated in March/April 1993 using cultivation treatments shown (Results section - Table 15) and the parsnips drilled in late April. The crop was given standard commercial inputs, except nitrogen, and harvested on 25 October.

Site 5: The straw was incorporated in March/April 1993 with similar cultivations to site 4 and the linseed drilled in late April. The crop was given standard commercial inputs, except nitrogen, and harvested on 25 October.

Site 6: The straw was incorporated in March/April 1993 using a range of cultivation treatments (see Results section - Table 16) and the linseed drilled in late April. The crop was given standard commercial inputs, except nitrogen, and harvested on 25 October.

Assessments

Straw

The layout of the straw in each field was described. The depth, width of swath and width between swaths of straw were recorded on twenty samples. The quantity (t/ha) of straw was determined from 12 samples using 50 x 50 cm quadrats.

Cultivations

The effectiveness of each tillage operation was assessed in terms of its ability to either mix or invert the straw and of the interaction between these two operations and performance reliability.

These assessments were augmented by measurements of tractor forward speed, fuel use and wheel slip. Fuel use was converted to engine power, and together with work rate, allowed the energy requirements for each operation to be calculated.

In addition to the replicated treatments at sites 1 and 2, non-replicated plots were set up to look at the effect of the same implement but in different combinations and sequences. All cultivation operations at Site 1 were conducted with the strategy of identifying the minimum input necessary to provide complete inversion of the straw. All the inversion implements were operated at around 225 mm depth, the discs at between 100 and 150 mm and rotovator at 50 mm depth. The Rotadigger was set at 125/250 mm for the rotor and tines respectively except when the thickness of straw prevented this depth of operation being achieved by virtue of blockage under the chaincase.

At Site 2 a further strategy was applied to determine whether additional pre-mixing would have any benefit in term of crop yield. Also the level of mixing in each treatment was the minimum to allow each inversion machine to work successfully.

At Sites 4, 5, 6 the straw was chopped after removal from the carrot bed and assessments made as to the success of this operation. Seven different levels of premixing were evaluated using commercially available implements and tined type implements were included with two different designs of pto power driven horizontal rotors. Depth of ploughing was around 250 mm and the discs operated up to 200 mm. The tines were used at the maximum depth for their underbeam clearance, progressively up to 250 mm. The powered machines were able to achieve depths of between 100 and 150 mm depending on the division of straw by the chaincase or bout dividing discs.

Crop

Site 1: Linseed The mean length of unchopped straw was recorded on 200 straws. The percentage of lignin in straw samples before and after incorporation (spring 1992 and 1993 respectively) was determined in laboratory analysis. This showed the relative breakdown rates of straw after cultivation. The linseed plant population was recorded on 12 May using four 20 x 50 cm quadrats/plot. The crop height of 6 plants/plot was recorded on 25 June. A crop uniformity score (0-10, where 0 = non uniform and 10 = uniform) was recorded on 18 August. At harvest on 8 September, yield was determined by combine harvester on 2.8 m x 15 m plots, and then corrected to 91% dry matter. The yields of observation cultivation treatments were also determined.

Site 2: Wheat The plant population was recorded on 8 May using three 25 x 50 cm quadrats/plot. The crop height was measured on 3 July on 6 plants/plot. The yields and specific weights (corrected to 85% dry matter) were determined by harvesting 2.8 m x 12 m plots on 1 September 1992. The yields of observation cultivation treatments were also recorded. In 1993, the dry weight of combining peas was recorded.

Site 3: Cabbage The mean length of both chopped and unchopped straw was recorded on 200 straws. The mean head weights of cabbage were recorded using 40 heads/plot.

Site 4: Parsnips The mean weight of straw was determined on 20 samples of straw. Crop vigour on 1 July 1993 was recorded (0-10, where 0 = dead, 10 = healthy, green and vigorous). Plant population was recorded on 1 July. At harvest on 25 October, parsnips were graded into diameter size grades (<35 mm, 35-65 mm, and over 65 mm) and weighed. They were also assessed for misshapen and rotten roots.

Site 5: Linseed A plant count was made on 30 June 1993. Crop height, fresh and dry weight were recorded on 30 June. It was not possible to combine harvest this experiment due to persistent wet weather. Hand-harvested samples were taken on 30 September 1993.

Site 6: Linseed A plant count was made on 30 June 1993. Crop height, fresh weight and dry weight were also recorded on that date. It was not possible to combine harvest this experiment due to persistent wet weather. Hand-harvested samples of plants were taken on 30 September 1993. The linseed capsules were extracted and weighed separately from the stems; both fresh weights and oven-dried at 80° for 48 hours.

DESIGN AND STATISTICAL ANALYSIS

Each site had one replicated experiment. These designs were split plot with straw removal/incorporation using cultivation sequences on main plots, which were split for nitrogen rate and timing. There were three replicates on site 1, four on sites 2 and 3, two on sites 4 + 5 and three on site 6. Data from these experiments were suitable for statistical analysis. At sites 1 and 2, there were also several non-replicated 'observation' treatments for cultivation sequences only.

RESULTS

Straw layout and quantity

Site 1: The straw lay in high swathes 45 cm high, 0.9 m wide with 1.8 m between swaths. The mean straw length prior to chopping was 134 mm. The mean weight of straw was 40 t/ha.

Site 2: The straw was in low, broad swaths; 21 cm high, 1.4 m wide with 2 m between swaths. The mean straw length prior to chopping was 225 mm. There was 35 t/ha of straw on average.

Site 3: The straw lay in low, broad swaths; 14 cm high, 1.3 m wide with 1.7 m between swaths. The mean length of straw prior to chopping was 252 mm (range 30-450 mm). After chopping, the mean length was 79 mm (range 10-350 mm). There was 16 t/ha of straw.

Site 4: The straw lay in trampled 'swaths' between 45 and 140 cm in width, with 2 m between the swaths. Depth of straw was very variable at 1-32 cm. The weight was estimated at 20 t/ha.

Site 5: The straw layout was similar to site 4.

Site 6: The unchopped straw ranged from 8 to 22 cm deep. It was in swaths 1.5-1.6 cm wide with 2 m between swaths. It was severely trampled in places. There was approximately 40 t/ha of straw.

The cultivation strategies and their effects on subsequent cropping are discussed for each site.

Site 1 (1992, carrots - 40 t/ha straw; 1993, linseed; 1994, set aside)

Cultivation strategies

These are shown in Table 3. There were two main problems with the inversion process, firstly ensuring that the residue could pass unhindered through the inversion device and secondly achieving complete burial of the straw. Appropriate implement design (ie trashboards rather than skims on the plough and increased clearances) ensured unhindered flow together with adequate straw chopping and pre-mixing to give complete burial. Total burial could be compromised by unchopped straw remaining at the base of bed wheelways and being brought to the surface by the inverting implement.

Increased working depth of the twisted share tine can lift the straw to the surface during premixing and therefore avoid this problem.

The comparative energy requirements are shown in Figure 1 and the machinery specifications are given in Appendix II. From Table 3 it can be seen that treatments 3 and 4 could be used on a commercial scale and total inversion was only achieved with treatment 4. This system required six times the energy needed to produce inversion of the bare soil.

Table 3. Cultivation sequences and strategies on site 1: sandy loam soil in 1992 (subsequently in linseed).

Straw treatment	Straw pre-mixing	Straw inversion	Strategy
Replicated treatments			
1. Removed	Bare ground (control)	Mouldboard plough	Control treatment
2. Chopped	Disc harrow x 1 Press x 1	Mixaplough	To apply the minimal amount of pre-mixing to enable Mixaplough to work. Some straw was left on surface. Occasional blockages.
3. Chopped	Disc harrow x 2 Press x 2	Mouldboard plough	To apply the minimum amount of pre-mixing to enable the mouldboard plough to work. 99% inversion.
4. Chopped	Disc harrow x 4 Press x 4	Mouldboard plough	What advantages can this extra amount of pre-mixing have? It enabled the Mouldboard plough to invert straw very well. Negligible straw on surface.
Observation treatments			
5. Not chopped	Rotadigger x 1 Press x 1	Mixaplough	What is the potential of a powered cultivator versus a draught cultivator? The rotadigger mixed the unchopped swath well. 100% burial of the straw with no blockages.

6. Not chopped well	Rotavator x 1 Press x 1	Mixaplough	Would the Rotavator be as effective as the Rotadigger? It mixed the unchopped swath into the firm soil surface. 100% burial of the straw with the Mixaplough.
7. Not chopped	Rotadigger x 1 Press x 1	Mouldboard plough	Strategy as for 5. 95% burial of the straw. Build up of straw between bodies which when released, formed thick clumps on surface.
8. Not chopped	Rotavator x 1 Press x 1	Mouldboard plough	Strategy as for 7. 95% burial of the straw but some blockages.
9. Not chopped unchopped	Disc harrow x 4 Press x 4	Mixaplough	Could the disc harrow be effective in straw? 100% inversion achieved with no blockages.
10. Not chopped	Disc harrow x 4 Press x 4	Mouldboard plough	98% inversion achieved at a lower forward speed than 4. Chopping improves inversion and rate of work.
11. Not chopped	Rotadigger x 1 (across swath) Press x 1	Mixaplough	Can the direction of premixing affect the overall result. Less burial than 5 (98%) but no blockages.
12. Chopped	Rotadigger x 1 (across swath) Press x 1	Mouldboard plough	Build up of straw on chaincase of Rotadigger whereas in 7 chaincase skid between swaths. 95% burial, some left on surface.

13. Chopped	Rotavator x 1 (across swath) Press x 1	Mouldboard plough	Could the rotavator work across the swath? Some straw build up but chaincase narrower. 95% inversion. Occasionally, straw riding above trashboard and left on surface.
14. Chopped	Rotavator x 1 Press x 1 Disc harrow x 1 Press x 1	Mouldboard plough	Would an additional mixing improve burial? 100% inversion (improvement compared with 8).

Site 1 - Linseed (cont)

Plant population

The mean plant population of linseed was 589/m² and there were no significant differences between cultivation or nitrogen treatments.

Crop height

The results are shown in Table 4. On the bare plots, the plants were taller ($P<0.05$) than on the plots where straw had been incorporated. All straw incorporated treatments gave similar mean crop heights. There was no effect of nitrogen treatment on crop height.

Table 4. Effects of cultivation and nitrogen treatments on plant height (cm) of linseed on Site 1 on 25 June 1992.

Treatment	Nitrogen (kg/ha) and application timing *					
	100 A	130 A	130 B	160 A	160 B	Mean
1 Bare, MP	41.4	41.9	42.2	44.7	42.8	42.7
2 Chopped, DXx1, Px1, MX	41.4	41.4	40.8	41.1	40.3	40.7
3 Chopped, DHx2, Px2, MP	41.7	40.8	40.3	40.8	40.0	40.8
4 Chopped, DWx4, Px4, MP	39.2	40.3	40.0	39.7	39.4	39.8
Mean	40.9	41.1	40.8	41.6	40.6	41.0
L.S.D. (5%) between cultivations					1.09	
L.S.D. (5%) between N treatments					NS	
L.S.D. (5%) between N x cultivations					NS	

*A = Whole N rate applied to crop
B = Part of N rate applied to straw, rest to crop.
(ie. 130 kg/ha = 30 to straw + 100 to crop)
160 kg/ha = 60 to straw + 100 to crop)
MP = mouldboard plough
DH = disc harrow
P = press
MX = mixaplough

Crop uniformity

Where straw had been removed, the crop appeared even with a uniform stand with plants of a similar height (Table 5). Where straw had been incorporated, the crop uniformity score was lower ($P<0.05$). Treatments 2 and 3, where minimal pre-mixing cultivations had been used, gave lower ($P<0.05$) uniformity scores than those plots where increased pre-mixing cultivations had been done (Table 5).

Table 5. Effects of cultivation and nitrogen treatments on crop uniformity of linseed on Site 1 on 18 August 1992.

Treatment	Crop uniformity score # Nitrogen (kg/ha) and application timing * 100 A	130 A	130 B	160 A	160 B	Mean
1 Bare, MP	9.3	9.0	9.7	9.7	9.0	9.4
2 Chopped, DXx1, Px1, MX	5.3	6.0	6.7	5.3	6.3	5.9
3 Chopped, DHx2, Px2, MP	4.3	6.0	7.0	7.3	5.3	5.9
4 Chopped, DWx4, Px4, MP	7.3	7.7	7.0	8.0	7.7	7.4
Mean	6.6	7.2	7.6	7.6	7.1	7.2
L.S.D. (5%) between cultivation treatments				1.57		
L.S.D. (5%) between N treatments				0.65		
L.S.D. (5%) between cultivation x N treatments				1.76		

# 0 = non uniform
10 = very uniform
*A = Whole N rate applied to crop.
B = Part of N rate applied to straw, rest to crop.

Yield

The yield of linseed (Table 6) was lower ($P<0.05$) where straw had been incorporated. There were no differences between the straw incorporated treatments. There were high ($P<0.05$) yields of linseed where 130 or 160 kg/ha of nitrogen had been used compared with 100 kg/ha. It is not known whether the limit of the nitrogen response was observed in this experiment. There was no benefit from applying part of the nitrogen to the straw prior to ploughing.

Table 6. Effects of cultivation and nitrogen treatments on yield (t/ha) of linseed on Site 1 in 1992, corrected to 91% dry matter.

Treatment	Nitrogen (kg/ha) and application timing*					
	100 A	130 A	130 B	160 A	160 B	Mean
1 Bare, MP	1.5	1.8	1.8	2.1	1.9	1.8
2 Chopped, DHx1, Px1, MX	1.2	1.5	1.2	1.5	1.4	1.3
3 Chopped, DHx2, Px2, MP	1.0	1.5	1.2	1.7	1.3	1.3
4 Chopped, DHx4, Px4, MP	1.0	1.5	1.1	1.7	1.3	1.3
Mean	1.2	1.5	1.4	1.8	1.5	1.4
L.S.D. (5%) between cultivation		0.15				
L.S.D. (5%) between N treatments		0.12				
L.S.D. (5%) between N x cultivation		NS				

*A = Whole N rate applied to crop
B = Part of N rate applied to straw, rest to crop.
(ie. 130 kg/ha = 30 to straw + 100 to crop)
160 kg/ha = 60 to straw + 100 to crop)
MP = mouldboard plough
DH = disc harrow
P = press
MX = mixaplough

Site 1 - observational treatments - none replicated

The effects of the cultivation sequences on mean crop height and yield on the observation plots on Site 1 are shown in Table 7. The yields were higher on these plots as the farmer applied extra nitrogen (totalling c. 150 kg/ha N).

Table 7. Effects of cultivation sequences on mean crop height (cm) and yield (t/ha) of linseed on unreplicated observation plots on Site 1 in 1992.

Treatment (non-replicated)	Mean crop height (cm)	Yield (t/ha)
5	42.0	2.0[1]
6	43.5	2.1[1]
7	42.5	2.1[1]
8	41.0	2.1[1]
9	43.0	2.1[1]
10	41.5	2.1[1]
11	42.5	2.2
12	41.5	1.5
13	41.5	1.6
14	40.5	1.8

1 mean of two cuts taken

Further monitoring of Site 1

Straw degradation

Site 1 went into set-aside after linseed. Samples of straw were taken to determine relative decomposition rates. Baseline measurements were taken prior to ploughing down the straw in 1992. The mean percentage of straw that was lignin was 16.4% on Site 1.

When samples of the straw were analysed a year later, in spring 1993, the overall levels of lignin had increased (Table 8). There were no significant differences between the treatments. The straw decomposition rate was not affected by the level of pre-mixing cultivation. It was not increased by the addition of extra nitrogen to the crop.

Table 8. The mean percentage of lignin in straw on 1993.

Cultivation	% Lignin Nitrogen # (kg/ha) 100	 160	 Mean
Low (chopped, DHx1, Px1, MX)	25.3	25.8	25.5
Medium (chopped, DHx2, Px2, MP)	25.0	25.6	25.3
High (chopped, DHx4, Px4, MP)	20.7	17.8	19.2
Mean	23.7	23.1	23.4
L.S.D. (5%) between cultivation treatments			NS
between N treatments			NS

N applied to crop

Set-aside cover in spring 1993

The natural regeneration of plant species had established on the area of the 1992 experiment. All cultivation treatments, including the bare plots, had a similar level of plant covering 45.0% of the ground. There were no differences between treatments.

Site 2 (1991, carrots - 37 t/ha straw; 1992, spring wheat; 1993, combining peas)

Cultivation strategies

The visual effects of the cultivation strategies are shown in Table 9. At this site, the straw was spread prior to chopping to even out the heaps left after the removal of the polythene membrane. Chopping was carried out at an angle of 90° to the beds to enable the rotor to follow more closely to the soil surface. Three different inversion techniques were evaluated and the appropriate amount of pre-mixing was carried out to ensure unhindered flow of residue through each device. The Rotadigger was used very effectively as the initial pre-mixing operation on each replicated treatment (2-4). Further mixing was carried out using the disc harrow on treatments 2 and 4 and treatment 3 had further passes using the disc harrow and Rotadigger. In some cases, less then 100% burial of the straw was caused by the share of the inversion devices bringing unchopped straw from the base of the bed wheelways to the surface. A tining operation at the appropriate depth was required to break up this wet layer of straw and bring it nearer to the surface for eventual inversion. The resultant mix achieved by the Rotadigger was much better than two discings and the two rear tines were able to do an effective subsoil operation and assist in mixing up of the unchopped straw layer at depth. In all cases, a further discing/tining on each treatment would have enabled all the inversion devices to achieve 100?% burial. The 97-98% burial caused no problems in terms of establishing the following crop. The land packer/press was used extensively after each pre-mixing operation to firm the straw/soil profile which improved the effectiveness of the following operations.

The comparative energy requirements are shown in Figure 2. The mouldboard plough treatment required similar levels of energy as at Site 1 (Figure 1). The mixaplough required an additional 80 kWh/ha at this site without achieving 100% burial. The Square Plough needed extra pre-mixing which accounted for the additional 50 kWh/ha of energy above the mouldboard plough. All these treatments could be used commercially and the burial could also be improved by machinery modifications as explained in Appendix III.

Some of the observation treatments 5-15 show that different combinations of implements can achieve acceptable levels of pre-mixing for the inversion devices already described to give adequate straw burial. Treatments 11-15 could also be used in a full commercial operation on this soil type.

A detailed list of machinery specifications are given in Appendix II.

Table 9. Cultivation sequences and strategies on Site 2: sandy loam soil in 1992 (subsequently in winter wheat).

Straw treatment	Straw pre-mixing	Straw inversion	Strategy
Replicated treatments			
1. Removed	Bare ground (control)	Mouldboard plough	Control
2. Spread with a Fahr centipede and chopped	Rotadigger x 1 Press x 1 Disc harrow x 1 Press x 1 Disc harrow x 1 Press x 1	Mouldboard plough (225 mm)	Using a combination of powered and draught implements, this was the amount of pre-mixing required to enable mouldboard plough fitted with trashboards to achieve 98% inversion without blockages. Some unchopped straw in the base of wheel ruts was brought to the surface by ploughing.
3. Spread and Chopped	Rotadigger x 1 Press x 1 Disc harrow x 1 Press x 1 Rotadigger x 1 Press x 1	Square plough (225 mm)	To apply the minimum amount of mixing for the Square plough to work. This was more than the mouldboard plough or Mixaplough. This sequence of pre-mixing allowed the square plough to bury 98% of the straw.
4. Spread and chopped	Rotadigger x 1 Press x 1 Disc harrow x 1 Press x 1	Mixaplough (200-250 mm)	To apply the minimum amount of mixing for the Mixaplough to work. It buried 97% of straw with reduced pre-mixing cultivations. The soil surface was slightly more ridged, and needed levelling by further cultivations.

Observation treatments - reduced pre-mixing cultivations (none replicated)

5. Spread and chopped	Rotavator x 1 Press x 1	Square plough	What is the minimum level of pre-mixing required in spread straw? Unacceptable blockages occurred with this inadequate pre-mixing.
6. Spread and chopped	Rotavator x 1 Press x 1 Disc harrow x 3 Press x 1	Square plough	Strategy as for 5. This gave a good level of straw inversion with no blockages.
7. Spread and chopped	Rotadigger x 1	Mouldboard plough Press x 1	What is the minimum level of pre-mixing before the mouldboard plough? Unacceptable blockages occurred during ploughing.
8. Spread and chopped	Rotadigger x 1 Press x 1	Mixaplough	Strategy as for 7. Blockages occurred when the straw was lifted from the bottom of the ruts and wedged under the vertical disc support arm. Tining could help alleviate this.
9. Spread and chopped	Rotadigger x 1 Press x 1 Disc harrow x 1 Press x 1	Mixaplough	Strategy as for 7. The extra pre-mixing operation compared with 8 helped to avoid blockages.
10. Spread and chopped	Rotadigger x 1 Press x 1 Disc harrow x 1 Press x 1	Mouldboard plough	Mouldboard ploughing with the same mix as 9. Most of the residue was inverted at low (3 km/hr) forward speeds, but too slow for commercial operation.

Observation treatments - increased pre-mixing cultivations (none replicated)

11. Spread and chopped	Rotadigger x 1 Press x 1 Rotadigger x 1 Press x 1	Mouldboard plough	To determine whether chopping and increased pre-mixing would improve the performance of the mouldboard plough. This sequence gave an excellent degree of mixing through the profile and 100% inversion.
12. Spread and chopped	Disc harrow x 4 Press x 4 Disc harrow Press x 1	Mouldboard plough	After 4 passes with both disc harrow + press, the mix was not as good as with the Rotadigger (11). A further pass with the disc harrow gave a similar effect as 11. The plough inverted well.
13. Spread and chopped	Rotavator x 1 Press x 1 Rotavator x 1 Press x 1 Disc harrow x 2 Press x 2	Mouldboard plough	Strategy as for 11. This amount of pre-mixing was equivalent to that achieved by 11. Two passes with the Rotavator were not as effective as two passes with the Rotadigger mainly due to reduced depth of operation and no tines for deeper soil loosening/mixing.
14. Straw as field (uneven distribution)	Press x 1 Rotavator x 1 Press x 1 Disc harrow x 3 Press x 3	Mouldboard plough	This amount of pre-mixing was inferior to the previous three treatments. Without spreading and chopping straw, an extra pass with disc harrow and two passes with press were required.

15. Straw as in field (very uneven distribution)	Disc harrow x 4 Press x 4 Disc harrow x 4 Press x 4	Mouldboard plough	Strategy as for 14 but using passive cultivation. This degree of mixing gave a similar effect to 11. However, during ploughing some unmixed, wet straw from at the base of deep ruts and
		was pulled to the surface	

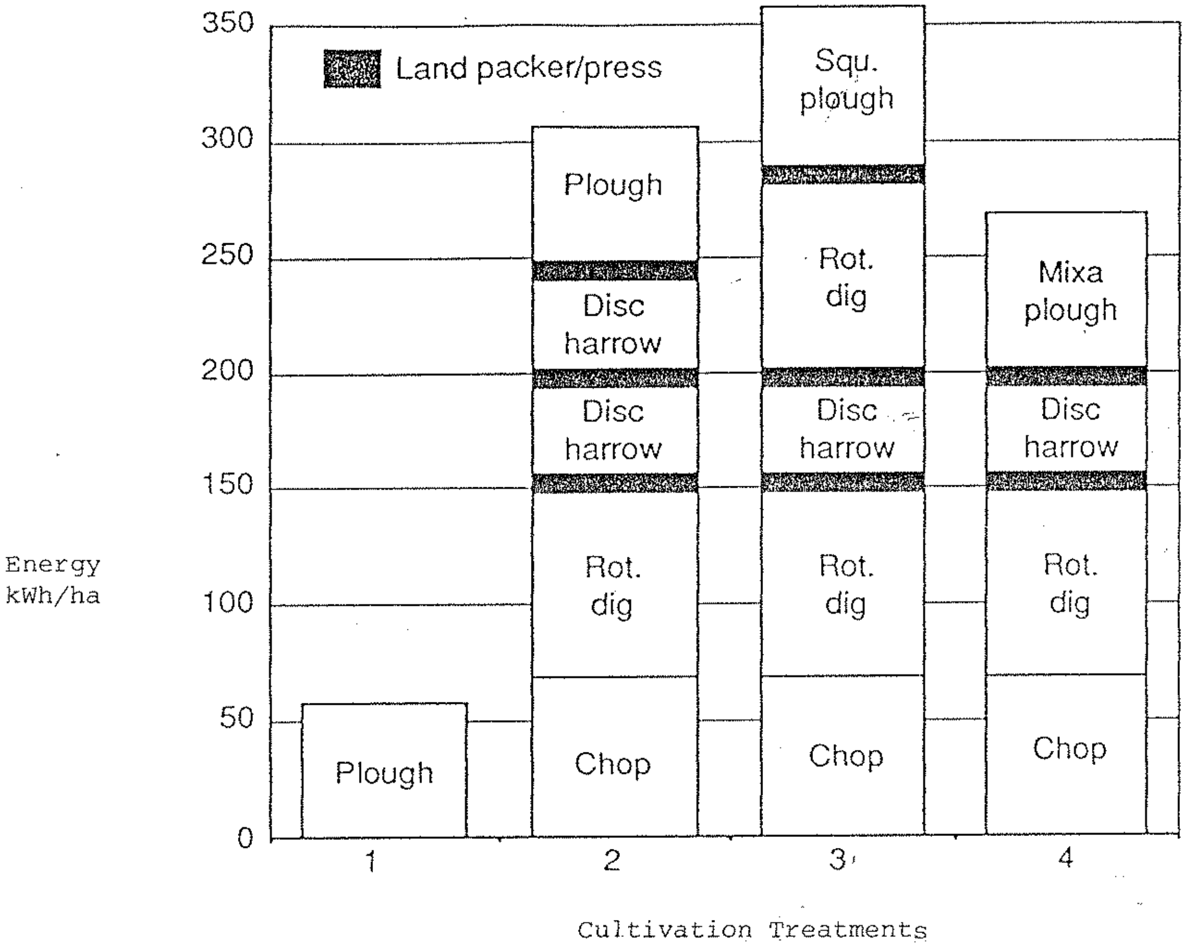

Figure 2. Energy of cultivation systems at Site 2.

Plant population

The mean plant population of spring wheat was 342 plants/m^2. There were no significant differences between either the cultivation or the nitrogen treatments.

Crop height and development

On 3 July, the mean crop height was 75.0 cm. There were no significant differences between either the cultivation or the nitrogen treatments.

When assessed on 7 May it was noted that the bare treatments were clearly discernible. They were a much darker green than the straw-incorporated plots and the plants slightly more advanced. On the bare plots, the soil was moist on top whereas all of the straw-incorporated plots appeared drier.

Yield

All cultivation treatments gave similar yields (Table 10) (see page 8). Applying nitrogen in one application to the crop at 190 kg/ha gave a higher ($P<0.05$) yield than applying it at 100 kg/ha. There was no benefit from applying part of the nitrogen prior to incorporation of the straw.

Specific weight

The specific weight (Table 11) was lower from the bare plots than from treatment 2 (minimal pre-mixing cultivations, followed by the mouldboard plough). The specific weight was lower ($P<0.05$) for the 100 kg/ha nitrogen rate than for the higher rates of application.

Table 10. Effects of cultivation and nitrogen treatments on yield (t/ha) of spring wheat on Site 2 in 1992, corrected to 85% dry matter.

Treatment	Nitrogen (kg/ha) and application timing*					
	100 A	150 A	150 B	190 A	190 B	Mean
1 Bare, MP	3.4	3.4	3.9	3.9	3.6	3.6
2 Chopped, RDx1, DHx2, Px3, MP	3.2	3.6	3.4	3.9	3.4	3.4
3 Chopped, RDx2, DHx1, Px3, SP	3.0	3.0	2.8	3.5	3.3	3.1
4 Chopped, RDx1, DHx1, Px2, MX	3.3	3.7	3.5	3.3	3.5	3.4
Mean	3.2	3.4	3.4	3.7	3.5	3.4
L.S.D. (5%) between cultivations		NS				
L.S.D. (5%) between N treatments		0.33				
L.S.D. (5%) between N x cultivations		NS				

* A = one application to the crop
B = split application, part to straw before cultivation, part to crop.
(i.e., 150 kg/ha = 50 to straw + 100 to crop
190 kg/ha = 90 to straw + 100 to crop).

Table 11. Effects of cultivations and nitrogen treatments on specific weight of spring wheat on site 2 in 1992.

Treatment	Nitrogen (kg/ha) and application timing					
	100 A	150 A	150 B	190 A	190 B	Mean
1 Bare, MP	73.8	75.1	75.7	75.6	76.0	75.1
2 Chopped, RDx1, DHx2, Px3, MP	76.3	76.6	77.4	75.8	76.9	76.6
3 Chopped, RDx2, DHx1, Px3, SP	75.7	77.0	76.1	76.0	76.6	76.1
4 Chopped, RDx1, DHx1, Px2, MX	75.9	76.1	76.2	75.8	76.2	76.0
Mean	75.1	76.2	76.4	75.8	76.4	76.0
L.S.D. (5%) between cultivations		1.10				
L.S.D. (5%) between N treatments		0.68				
L.S.D. (5%) between N x cultivations		NS				

Site 2 - observation treatments - none replicated

Table 12. Effects of cultivation treatment on yield (t/ha) of spring wheat on observation plots on 1 September 1992.

Cultivation treatment No.	Yield# (t/ha)
5	3.8
6	3.7
7	2.9
8	2.6
9	2.4
10	2.9
11	3.8
12	3.5
13	3.5
14	3.8
15	2.8

mean of 2 cuts

Further monitoring of Site 2

Site 2 went into combining peas in 1993.

The effects of cultivation and nitrogen treatments applied in spring 1992 were monitored in 1993. The results are shown in Table 13.

There were no cultivations or nitrogen treatment effects in evidence in 1993, on a pea crop sown 17 months after the straw had been incorporated.

Table 13. Effects of cultivation and nitrogen treatments on dry weights (t/ha) of combining peas on Site 2 in 1993.

Treatment	Nitrogen (kg/ha) and application timing *					
	100 A	150 A	150 B	190 A	190 B	Mean
1. Bare, MP	1.54	1.34	1.45	1.56	1.67	1.52
2. Chopped RDx1,DHx2,Px3,MP	1.36	1.55	1.33	1.73	1.45	1.46
3. Chopped RDx2,DHx1,Px3,SP	1.56	1.42	1.43	1.51	1.62	1.52
4. Chopped,RSx1,DHx1,Px2,MX	1.24	1.53	1.31	1.18	1.18	1.28
Mean	1.42	1.46	1.38	1.50	1.48	1.44
L.S.D. (5%)						NS

* A = whole rate applied to crop
  B = split application, part to straw, part to crop

Site 3 (1991, Bare - 16 t/ha straw; 1992, summer cabbage)

The mean head weight of summer cabbage was recorded at harvest on 27 July (Table 14). The incorporation of 16 t/ha of straw did not affect the yield of cabbage compared with where the straw had been removed. There were differences between the nitrogen treatments, with a lower ($P<0.05$) mean head weight where no nitrogen had been applied compared with the other treatments. There was no additional benefit from applying 400 kg/ha of nitrogen. There was no benefit from applying part of the nitrogen to the straw prior to incorporation.

Table 14. The effect of straw incorporation and rate and timing of nitrogen application on mean head weight of cabbage on Site 3 on 27 July 1992.

Nitrogen (kg/ha)	Mean head weight (g) Straw removed	Straw incorporated	Mean
Nil	916	887	901
200 (planting/top dressing)	1123	1142	1133
200 (to straw/planting)	1130	1020	1075
400 (to straw/planting/top dressing)	1256	947	1102
Mean	1106	999	1053
L.S.D. (5%) between two straw treatments			NS
L.S.D. (5%) between two N treatments			156.1

Site 4 (1992, parsnips - 20 t/ha straw; 1993, parsnips)

After parsnips, 20 t/ha of unchopped straw was incorporated by 15 April 1993. The list of cultivations used for each treatment is shown in Table 15. Parsnips were drilled on the site in late April. There were no treatment effects on crop vigour or plant population on 1 July.

When harvested on 25 October, the total yield was 59 t/ha, on average, and this was not affected by either cultivation or nitrogen treatment. There was, however, a tendency for the yield to be higher where at least 60 kg/ha of nitrogen was applied; this was true for both 'bare' and straw incorporated plots.

The yield of pre-packed sized parsnips (35-65 mm) is shown in Table 15. There were no significant cultivation effects. The optimum nitrogen rate for pre-packed roots was 60 kg/ha.

Table 15. Effects of cultivations and nitrogen treatments on yield (t/ha) of 35-65 mm parsnips.

			Yield (t/ha) N (kg/ha)			
Cultivations	0	60	120	180	240	Mean
1. Bare, MP#	13.7	19.1	15.9	14.4	4.3	13.5
2. Unchopped, Wing Z, Px2, DHx1, MP*	17.8	23.1	17.0	15.3	10.5	16.7
3. Unchopped, Wing Z, DHx2, Px3, MP#	17.5	32.8	21.0	14.0	15.3	20.1
4. Unchopped, Wing Z, Strawboy, Rota-labour, Flat Roll, MP*	14.9	19.4	17.0	12.1	8.1	14.3
5. Unchopped, Wing Z, Rototiller, Px2, MP#	33.7	26.2	28.5	16.9	13.5	23.8
Mean	19.5	24.1	19.9	14.6	10.3	17.7

L.S.D. (5%) between cultivations	NS
between N treatments	(6.15)

* Plough 30/44

\# Plough 27.5/39

The presence of incorporated straw did not affect the shape of parsnips even though there were higher concentrations of straw in places. There were, on average, 16% of fanged roots but with no significant treatment effects.

Site 5 (1992, parsnips - 20 t/ha straw; 1993, linseed)

The cultivations used to incorporate the unchopped straw were the same as Site 4 (Table 15). The whole site was very deeply rutted from the harvesting operation. The incorporation of 20 t/ha of straw did not affect early crop development nor crop yield. There were no differences between the cultivations in either early crop growth or yield.

The crop responded to 120 kg/ha of nitrogen both in the presence and absence of straw.

Site 6 (1992, Carrots - 40 t/ha straw; 1993, linseed)

Straw chopping

The straw was chopped after removal from the carrot bed using a tractor three point linkage mounted multi-purpose machine. This was fitted with straight straw-blades, fan plates and fixed knives. By using one row of fixed knives an adequate chop length of 4" (100 mm) was achieved and the overall power requirement reduced.

The straw had been tipped off the polythene membrane prior to harvesting the carrots and then moved sideways by a conventional straw remover. In the absence of a polythene membrane, the same straw remover could have lifted the straw directly from the top of the carrot bed and moved it sideways in one operation.

The surface of the soil after harvesting was uneven and extensively rutted by the trailers used to transport the carrots from the harvester to the packhouse. The straw removed from the bed was then deposited onto this surface, some of which fell into the bottom of the ruts. The straw was often further wheeled into the soil by subsequent harvesting operations with a percentage still remaining in the bottom of the bed wheelways.

At this point, it was only possible to chop 50-60% of the total residue for the reasons explained above, the remainder being inaccessible to the chopping mechanism. Improved management practices could help alleviate the problem ie firming the soil surface after harvesting, chopping the straw immediately after removal and increasing the widths of tyres on the transport vehicles.

Cultivation sequences

Seven different level of pre-mixing were evaluated in a fully replicated trial at this site. These ranged from ploughing the chopped straw without pre-mixing to an exceptional mix using discs, tines and horizontal powered rotors. These are shown in Table 16. The heavy disc harrow (160 kg/disc) was used as the first pass on most treatments to cut through the unchopped straw layer left after only chopping 50-60% of the residue.

All cultivation implements used at this site were commercially available. The strategies behind the seven systems tried were as follows:-

a. To identify the minimum mix that would allow the new improved mouldboard plough with 44 in (1.12 m) interbody and 30 in (762 mm) underbeam clearance to achieve 100% burial.

b. To create two different levels of mixing using the disc harrow and tines with twisted shares and or wings. The tines being used to lift out unchopped straw from the base of the rutts and wheelways.

c. To evaluate a system using tined cultivations only, after an initial pass of the disc harrow; to determine their overall mixing capabilities.

d. To determine the mixing capabilities of power driven rotors both on their own and in conjunction with tines to lift out the unchopped straw from lower in the soil profile.

e. To create an exceptional mix treatment using discs, tines and powered rotors to see if their is any benefit to subsequent crop growth and yield.

As explained in the previous years trials, firming the straw and soil was crucial to the success of subsequent mixing implements except when tines were used to lift up unchopped residue. The heavy land packer (1 tonne/metre^2) was able to achieve this consolidation which was most beneficial in maximising the amount of mixing achieved by subsequent cultivation implements and is a very necessary part of each treatment. Pressing before ploughing creates a firmer surface for optimum soil/residue flow across the skim coulters therefore improving total inversion. Even pressing the unmixed chopped straw was beneficial in terms of achieving total straw burial.

In this trial, both of the ploughs were fitted with larger skim tops to prevent residue jumping over the top of the skim and collecting on the skim leg. This could then be later released in large wads and remain on the ploughed surface therefore compromising inversion.

A detailed description of all the implements used is contained in Appendix II.

Table 16. Cultivation systems for Site 6 in 1993.

	Straw pre-mixing	Comments
1.	Straw removed, Plough (27.5/39)	
2. Zero (2) no mix (2a) min mix	Press Rotalabour Plough (30/44)	Minimum energy level to give complete burial without pre-mixing. A single pass of the Rotalabour was necessary on one replicate to break up the unchopped straw immediately above the soil surface.
3. Minimum Mix	Disc harrow - Press Disc harrow Strawboy (flexible tine/twisted share) - Press Plough (30/44)	Strawboy used to lift unchopped straw from the base of the wheel ruts. The plough with extra clearance and large wrap round skim tops is very able to completely bury the residue. Improved distribution of straw through the soil profile than 2.
4. Intermediate mix	Disc harrow - Press Disc harrow Wing Z (rigid tine/twisted share/wings) - Press Disc harrow - Press Disc harrow - Press Plough (27.5/39)	The two additional passes of the disc harrow improved the degree of mix. Wing Z used to lift up unchopped straw, less clearance 27.5 in (699 mm) underbeam and 39 in (9.91 mm) interbody clearance coped well and achieved complete burial.
5. Intermediate mix	Disc harrow - Press Wing Z (rigid tine/twisted share/wings) Strawboy (flexible tine-twisted share) - Press Wing Z - Press Strawboy - Press Plough (30/44)	Could the two tined mixing implements achieve acceptable levels of mixing. A very similar mix to treatment 4 from less expensive implements. Very easily buried using the extra clearance plough.

6. Intermediate/maximum mix	Disc harrow - Press Rotalabour - Press Rotalabour - Press Plough (30/44)	The mix was slightly better than treatment 4 or 5, but the plough brought up unchopped straw from bed wheelways. Tining between passes of Rotalabour would have improved overall result. Burial good.
7. Maximum mix	Disc harrow - Press Rotatiller Wing Z (rigid tine/twisted share/wings) - Press Rota tiller Strawboy (flexible tine/twisted share) - Press Plough (27.5/39)	Tines used after each pass of the powered machine. Improved level of mixing than 5 or 6. Lower clearance plough could adequately deal with the straw/soil mix. 100% burial.
8. Exceptional mix	Disc harrow - Press Disc harrow Wing Z (rigid tine/twisted share/wings) - Press Rotalabour Wing Z - Press Rotalabour Strawboy (flexible tine/twisted share) Rotalabour - Press Plough (27.5/39)	What are the benefits of a very extreme level of mixing? Does the crop receive any benefit? Can nitrogen levels be reduced. The crop could have been drilled after pre-mixing, without ploughing. Total burial of straw would have been possible using ploughs with 34 in (864 mm) interbody clearance.

50-60% of the straw was chopped for treatments 2-8.

System Energy Requirements

The labour requirement for each operation and the total requirement for each of the eight systems are shown in Figure 3.

Treatment 2 with no pre-mixing had the lowest energy requirement of all treatments where straw had been incorporated. The extra pass with the Rotalabour in 2a added 50 kWh/ha.

Treatment 3 using passive implements required an additional 100 kWh/ha compared with treatment 2; the degree of mix achieved from treatment 3 was sufficient for the mouldboard plough, with extra clearances and fitted with large wrap round skim tops, to achieve complete burial of the straw without blockages.

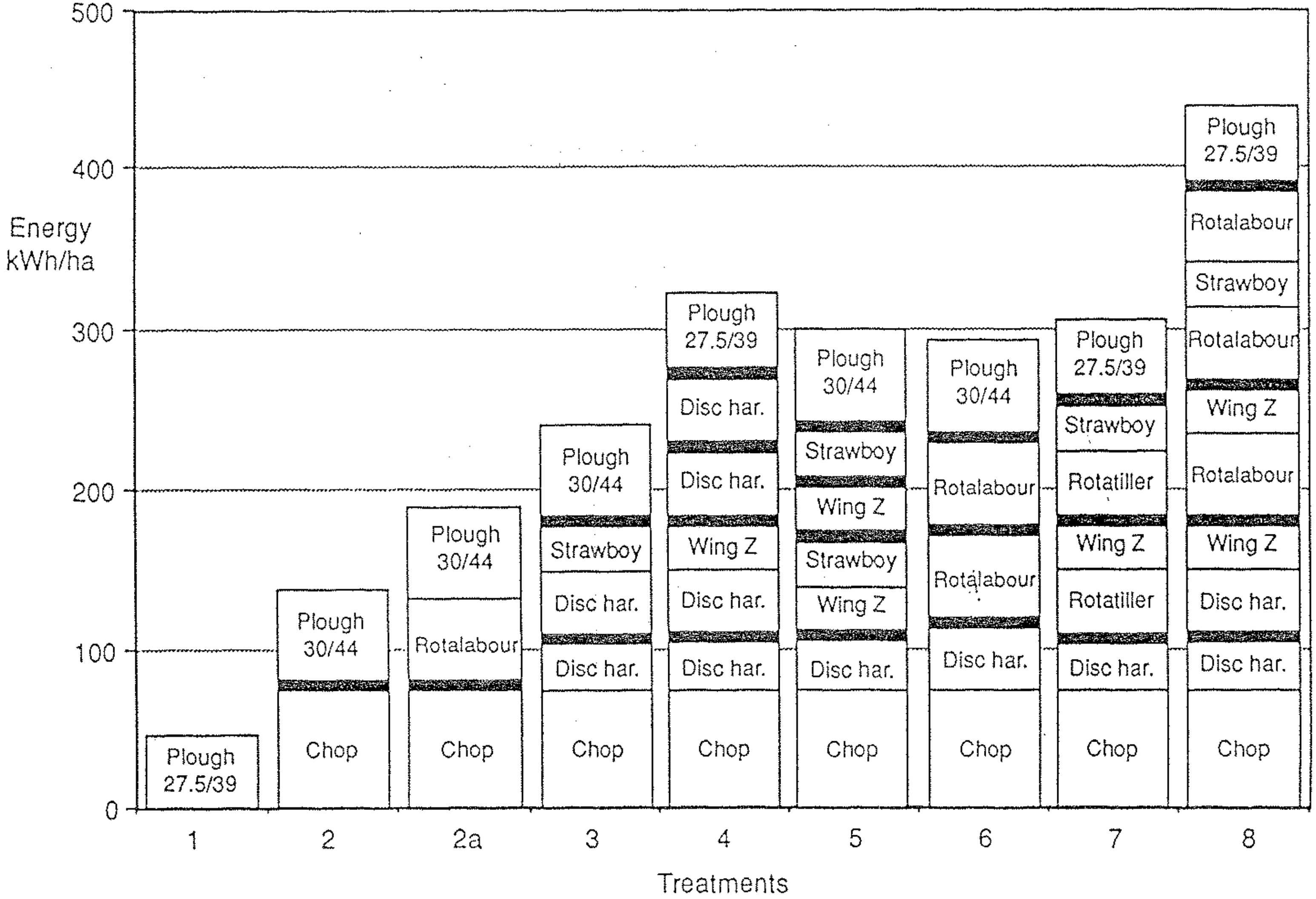

Figure 3. Energy of cultivation systems at Site 6.

Treatments 4, 5, 6 and 7 using predominantly discs, tines and two types of powered tillage all needed similar levels of energy with treatment 4 being the highest at 320 kWh/ha, over twice that required for treatment 2 (no mix). Similar levels of straw mixing were achieved in 4 and 5 which was considerably better than treatment 3. Treatment 7 was slightly better in terms of mixing than 4, the inclusion of a tined cultivator improved the degree of mixing by lifting the unchopped straw to the surface to be dealt with by the powered rotor. The Rotatiller (7) with a horizontal "pick tine" rotor required slightly less energy than the Rotalabour but depths may not be exactly comparable. Treatment 6 (Rotalabour) would also have benefited from the inclusion of a tined implement to lift up unchopped straw and this would increase the overall energy requirement by 26 kWh/ha; the mixing was comparable to that in treatment 5.

Treatment 8 required the highest energy of all treatments, over three times that of the chop/plough system in 2. The combination of the Rotalabour, disc harrow and tines gave an extreme mix into which the following crop could have been drilled without ploughing saving 48 kWh/ha.

The straw mixing treatments 4, 7 and 8 were successfully buried residues using a mouldboard plough with 27.5 in (699 mm) underbeam and 39 in (991 mm) interbody clearance fitted with skim coulters. Treatments 5 and 6 mixes were easily dealt with using the extra clearance plough and 100% burial achieved.

System Costings

The overall cost of each tillage treatment was calculated and these are shown in Figure 4. It was assumed that each of the treatments covered 200 ha.

Treatment 5 was less costly than 4 or 7 by £7-13/ha but the mix was not as good as 7. Treatment 3 with a relatively low cost £136/ha produced a degree of mix which the higher clearance plough could totally invert. Treatment 6 was lower in cost and quality than 7, but by using additional passes of tines would be very similar. Treatment 4 at nearly £200/ha produced a degree of mix which the lower clearance plough 27.5/39 could bury.

Treatment 2a showed that by reducing the mixing to one pass, large cost savings can be made. The high clearance plough 30/44 was able to give virtually 100% inversion of the residue, though the straw remaining in the base of the wheelways was sometimes brought to the surface by the plough. Treatment 2 with no pre-mixing was the lowest cost at £80/ha but total inversion was not always possible. Treatment 3 at £136/ha could be used on a full commercial scale with the percentage of the straw that was chopped at this site. Treatments 2 and 2a could be attempted commercially providing either the total volume of straw is less than 40 t/ha or if virtually all of the residue is chopped to lengths of 100 mm or less.

Crop development

There were on average 611 linseed plants/m² on 30 June with no differences between the cultivation treatments. There were large differences both in fresh weight and dry weight between the cultivation treatments, and between the two nitrogen treatments assessed on that date. All cultivation treatments had higher dry weights at 180 kg/ha rate of nitrogen (Table 17). There was also a significant interaction; the linseed plants from the bare ground and treatment 6 (intermediate-maximum mix) plots had relatively high dry weights even without nitrogen. It is not clear why this interaction happened.

The zero-minimum mix (treatment 2) gave similar high dry weights to the bare plots at 180 kg/ha and showed that this cultivation technique need not hinder crop development.

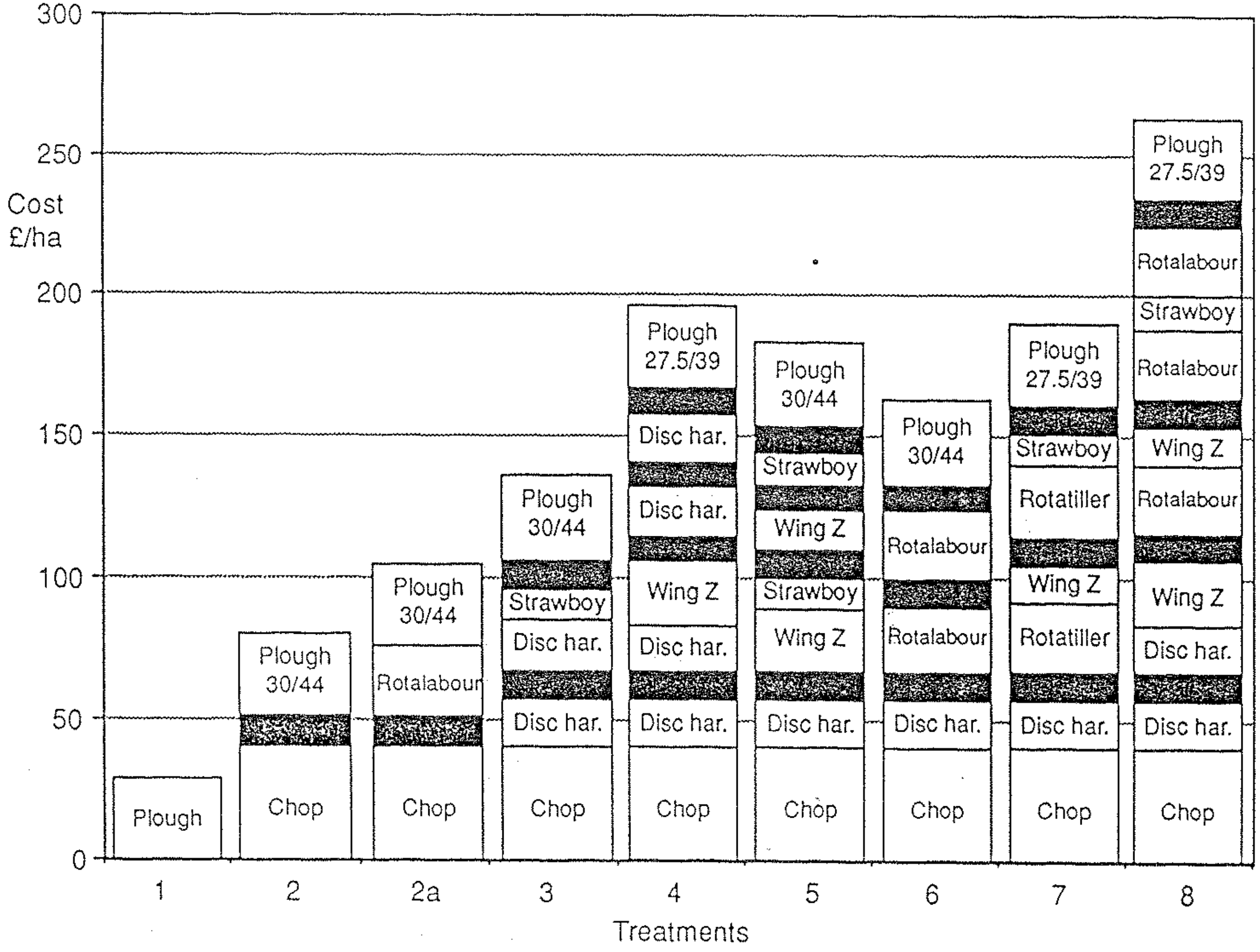

Figure 4. Comparative costs of cultivation systems (£/ha) on 2000 ha farm using data off Site 6.

Table 18. Interaction between cultivations and nitrogen on oven-dried dry weights (t/ha) of linseed plants on Site 6 on 1 July 1993.

Cultivation	Dry weight (t/ha) of linseed N (kg/ha) 0	180	Mean
1. Bare ground	0.34	0.50	0.42
2. Zero-minimum mix	0.16	0.55	0.35
3. Minimum mix	0.11	0.42	0.26
4. Intermediate mix 1	0.11	0.43	0.27
5. Intermediate mix 2	0.08	0.38	0.23
6. Intermediate-maximum mix	0.33	0.54	0.44
7. Maximum mix	0.07	0.37	0.22
8. Exceptional mix	0.09	0.48	0.29
Mean	0.16	0.46	0.31

L.S.D. (5%) between cultivation treatments	0.112
between nitrogen treatments	0.023
between cultivation x nitrogen treatments	0.120

Crop height

It was clear that where the straw had been incorporated crop growth was less uniform compared with where the straw was removed. There were areas of poor growth with stunted plants. The good and poor areas were recorded separately. Where straw was incorporated, mean crop height was reduced (Table 19). The effect was significant (P<0.05) for all cultivations except the intermediate-maximum mix plots (treatment 6). Further mixing caused a reduction in mean plant height, but it is not clear why this happened.

Table 19. Effect of cultivation treatment on crop height on 30 June 1993 on Site 6.

Cultivation	Mean plant height (cm)	Crop height (cm) Good areas	Poor areas
1. Bare ground	64.6	66	63
2. Zero-minimum mix	50.3	65	45
3. Minimum mix	54.7	62	45
4. Intermediate mix 1	53.3	64	40
5. Intermediate mix 2	51.9	62	35
6. Intermediate-maximum mix	58.8	64	37
7. Maximum mix	48.7	65	33
8. Exceptional mix	48.8	64	53
Mean	53.9	64	44
L.S.D. (5%)	9.01		

Crop yield

It was not possible to combine harvest this crop but hand-harvested samples were taken. Yield parameters of 'fresh total plant weight', and 'fresh weight of capsules' showed no effect of cultivation treatment. Cultivation also did not affect dry weight of linseed capsules (Table 20).

The nitrogen treatments greatly (P<0.001) affected yield of dry linseed capsules. There was a response up to 180 kg/ha of nitrogen. The response was similar for bare and straw-incorporated treatments i.e. there was no interaction.

Table 20. Effect of cultivation and nitrogen on dry weight of linseed capsules from harvest on 25 October 1993.

Cultivation	Dry weight (t/ha) of linseed capsules Nitrogen (kg/ha) 0	60	120	180	240	Mean
1. Bare ground	0.87	1.34	1.38	1.63	1.69	1.39
2. Zero-minimum mix	1.04	1.11	1.34	1.40	1.51	1.28
3. Minimum mix	0.91	1.21	1.60	1.76	1.55	1.41
4. Intermediate mix 1	0.73	1.22	1.57	1.88	2.04	1.49
5. Intermediate mix 2	0.91	1.62	2.02	2.12	2.32	1.80
6. Intermediate-maximum mix	1.00	1.57	1.83	2.08	2.09	1.72
7. Maximum mix	1.15	1.24	1.52	1.82	1.96	1.54
8. Exceptional mix	0.62	1.19	1.57	1.96	1.81	1.49
Mean	0.90	1.32	1.60	1.83	1.87	1.51
L.S.D. between cultivations						NS
between N treatments						0.200

DISCUSSION

The experiments showed that either 40, 37, 20 or 16 t/ha of straw could be incorporated successfully on the six sites, on sandy, silty and peaty loam soils. On five sites, the incorporation of straw caused no yield depression compared with where straw had been removed.There was a reduction ($P<0.05$) in yield of linseed from incorporating the straw rather than removing it on one site in 1992. This reduction in yield could be partly or wholly attributed to inadequate nitrogen, particularly on the 100 kg/ha nitrogen treatments. Where straw had been incorporated, low yields of linseed were recorded in the presence of 100 kg/ha of nitrogen (recommended rate) and even with 130 kg/ha of nitrogen, but less so where 160 kg/ha was applied.

Increasing the nitrogen applications tended to raise yields of both linseed and spring wheat in 1992 but it is not known whether the limit to the response was reached in either crop. In 1992, the summer cabbage did not respond to 400 kg/ha as compared with 200 kg/ha of nitrogen. In 1993, two crops of linseed and one of parsnips responded to 180 kg/ha of nitrogen both with and without incorporated straw on sandy loam soils at Indices 0.

There were no yield improvements in the crops in 1992 where part of the nitrogen requirement was applied to the straw prior to its incorporation. Instead, a yield reduction was observed, in most cases, but this was only significant ($P<0.05$) for the 160 kg/ha rate applied to linseed.

It would appear that some of the yield reduction caused by incorporating straw rather than removing it (for example, by burning) could be corrected by applying additional nitrogen to the next crop. It is possible that complete chopping of the residue may speed up the rate of decomposition of the straw so that the demand for nitrogen in terms of the straw may be earlier in the season. This might reduce the overall rate of nitrogen required by the crop to maintain yields at the level of the bare treatments.

All experiments on the mineral soils showed that increased pre-mixing cultivations could be a waste of energy and time. All crops performed relatively well given minimal pre-mixing cultivations, sufficient to allow a mouldboard plough to pass unhindered. Further reductions still appeared possible using the experimental Mixaplough although this tool will probably not be developed further. Modifications to improve the ability of the conventional mouldboard plough to invert trash will be the likely direction of machinery developments (see Appendix III).

A reduced pre-mixing cultivation system requires the use of an efficient straw chopping technique. The use of a straw chopper obviates the need for at least one pass of a disc harrow and press.

In these experiments, it proved difficult to chop straw which had already been trampled into soil during the harvesting operation. The timing of the straw chopping operation to ensure the straw is chopped prior to being trampled into ruts is very important.

The 3 experiments in 1992 followed a dry winter (186.7 mm rainfall from October 1991 to April 1992 compared with the 25-year mean of 292.1 mm recorded at Mepal, Cambridgeshire). The 3 experiments in 1993 followed a wet winter (359.0 mm of rainfall from October 1992 to April 1993).

CONCLUSIONS

1. The incorporation of 40 t/ha of straw reduced the yield of linseed in 1992 compared with where the straw had been removed. However, crop yields were not reduced in 1992 following the incorporation of straw at 16 t/ha (cabbage) or 35 t/ha (spring wheat). Similarly, there were no yield reductions in 1993 for linseed or parsnips following the incorporation of 20-40 t/ha straw.

2. Yield reductions caused by incorporating large quantities of straw could be eliminated by increasing nitrogen rates. In 1992, the linseed and spring wheat responded to the maximum rate of nitrogen applied, but it is not known whether the limit of response was reached. In 1993, all crops responded to 180 kg/ha nitrogen at Index 0 on sandy loam soils. This is higher than the ADAS recommendations for linseed and parsnips but the response was similarly high where straw had been removed off plots.

3. There was no benefit to any of the crops from applying part of the nitrogen to the straw.

4. Improving the technique of chopping the straw before it leaves the carrot bed is considered to be the key factor in reducing tillage inputs.

5. By using a purpose built machine to chop and spread the straw off the bed it is likely that savings of between £50 and £80/ha compared with current practice could be achieved depending on the initial cost, power requirement and workrate of the machine.

6. There appeared to be no improvements in crop yield where increased rather than reduced pre-mixing cultivations were employed. This shows potential for developing energy saving straw incorporation systems.

7. Inversion of the 40 t/ha of fully chopped residue will be possible using a mouldboard plough with 30" (760 mm) underbeam and 44" (1.12m) point to point clearance fitted with large wrap-round skim tops or trashboards.

8. Further evaluation of the chopping techniques will be required to establish power requirements and workrates together with any agronomic effects of non pre-mixing systems.

9. It is possible that if the straw can be fully chopped before incorporation then the levels of nitrogen applied to obtain maximum yields in the following crops could be reduced.

ACKNOWLEDGEMENTS

ADAS Arthur Rickwood and Silsoe Research Institute wish to thank the HDC for funding the project and also the farmers and growers who provided the sites for the experiments and demonstration.

Grateful thanks are also expressed to the following manufacturers for the loan of machinery to do the work:-

ROTATILLER	Ferrag Ltd, St Helens, Merseyside
ROTALABOUR	Howard G B Ltd, Wymondham, Norfolk
DISC HARROW	P J Parmiter & Sons Ltd, Tisbury, Wiltshire
MOULDBOARD PLOUGHS	Dowdeswell Engineering Company Ltd, Stockton, Rugby
GIANT LANDPACKER	Cousins of Emmeth Ltd, Wisbech, Cambs
WINGZ CULTIVATOR	
STRAWBOY CULTIVATOR	
STRAW CHOPPER	Kverneland (UK) Ltd, Rotherham, South Yorks

Appendix I: Questionnaire sent to carrot growers in 1991.

1. What is your area strawed down (area or % of total)?

2. Proportion of area strawed-down on each soil type
   - a. Sand
   - b. Peat
   - c. Silt
   - d. Other

3. What rate of straw do you apply?

4. What proportion of the strawed-down area is covered with black polythene?

5. Is any of the straw chopped before applying?

6. After harvesting how do you get rid of the straw?

7. What proportion is incorporated in - an average year?
   - 1990/91?

8. What techniques do you use to incorporate the straw and how many tractor operations are involved?

9. When you've incorporated the straw do you increase/decrease the rate of nitrogen fertiliser?

10. If you burn the straw how many times is the straw turned prior to burning it?

11. When you burn how much straw is left on the field (on average)?
12. What crops follow late-lifted strawed-down carrots?

Summary of replies to questionnaire

1. Of those growers who replied, most strawed-down a proportion of their crops. The overall average was about 30% of the total area.

2. Most strawed-down carrots are on sandy soils, with fewer on silt soils, and small quantities on peat soils.

3. The rates of straw used are 30-60 t/ha. The overall average is 40 t/ha or 40 Hesston-type bales/acre.

4. Growers either favour use of black polythene or not. Most do not use it. Where a grower uses it, he may cover 100% of his strawed carrots with it.

5. None chopped.

6. Most growers incorporate. When burning is attempted, it often only partially burns the straw which then has to be incorporated.

7. Approximately 65% over all replies.

8. 4-9 passes. Usually heavy, large disc harrows. Other tools used are rotaspike, power harrow (roterra), roll, progressive cultivator, chisel plough.

9. Most growers do not change the nitrogen rate. Two growers increased their N rate by about 30 kg/ha, perhaps by adding nitrogen to straw to 'assist in its breakdown'. One grower decreased the nitrogen rate. It is not always known whether the rate has been increased or decreased by the farmer once hired land is returned.

10. Most growers do not turn the straw. If they do, it is turned only once.

11. Range 10-65%.

12. Most favoured crops are linseed, peas, beans, carrots. Less favoured crops are sugar beet, brassicas, white turnips and potatoes.

Appendix II: Machinery specifications

Plough

Dowdeswell 5 Furrow Mouldboard Plough DP7. Fully mounted reversible plough with a 355 mm furrow-width, 990 mm point to point spacing and 685 mm underbeam clearance. Semi-digger U.C.N mouldboards are fitted with replaceable shins to protect the front edge. Adjustable trashboards are fitted to the top of each shin to skim off the top of each furrow slice and direct it towards the bottom of the furrow. An adjustable depth wheel is fitted towards the rear of the main frame. The total weight is approximately 1480 kg and the overall width is 1.78 m. Skim coulters can also be fitted in front of each plough body and these were used in the 1993 season.

Mixaplough

Silsoe Research Institute prototype one way machine made up to 3 modules spaced at 560 mm with 900 mm underbeam clearance, total machine width being 1.68 m. An adjustable depth wheel is fitted to the left of the modules on the main chassis frame.

Each module consists essentially of a 510 mm diameter vertical flat disc mounted in front of a shallow plough body, with a share width of 288 mm and the small mouldboard 260 mm long x 370 mm high. Behind this, a dished disc of 760 mm diameter and 80 mm concavity is mounted to give a disc angle of 30° and an inclination of 26°. It is fitted with an adjustable mouldboard-shaped scraper mounted in the ten o'clock position. A slatted deflector is mounted behind the rear edge of the concave disc and shaped to fit the circumference of the disc. Total weight of the machine is 1557 kg.

Disc Harrow (right-hand offset) - Parmiter Utah 350

This machine is 3.05 m wide and weighs 3182 kg giving approximately 160 kg/disc. It consists of two gangs of discs, each being made up from two separate axles and mounted one in front of the other on a main chassis frame to form an "A" shape when viewed in plan. The angle of each gang can be adjusted independently. The main chassis frame has a pair of hydraulically operated wheels mounted between the gangs for depth control and transport purposes.

Each disc 710 mm diameter is spaced at 305 mm on an axle of 55 mm diameter, each axle holding 5 discs making a total of 10 discs in each gang. The front gang of scalloped discs turn soil to the right and the rear gang of plain discs move soil back to the left to create a level finish.

Individual scraper assemblies which can be adjusted, are fitted to the disc gang horizontal support members to keep the concave face of each disc clean in moist conditions.

Rotary Digger - S.R.I. Prototype/Howard

This machine is 2.17 m wide. It consists of a horizontal rotor fitted with 9 vertical flanges spaced at 241 mm. A series of long shank "L" shaped blades are bolted to extension plates around the periphery of each flange, four right-hand blades on each flange to give a rotor diameter of 760 mm, blade mounting angle being 52°. The flanges are welded to the rotor tube so that each one rotates 20° from the previous one to form the rotor scroll which aids penetration. Drive from the tractor pto to the soil engaging blades is transmitted via a telescopic drive shaft, over load clutch, bevel gearbox, jackshaft and chain side drive. The gears in the back of the gearbox can be interchanged to give rotor speeds in the range 50-116 rev/min. Behind the main rotor are mounted three semi-subsoil tines spaced at 760 mm and positioned 850 mm behind the rotor-tube. Ejector tines 35 mm x 10 mm are mounted midway between the tips of the blades and the next flange to keep the centre of the rotor tube clean at the lower rotor speeds. The rotor speed used at both sites was 85 rev/min. Total weight of the machine is 862 kg.

Rotavator - Howard H.B. 100

This is a 2.56 m wide fully mounted implement weighing approximately 1200 kg. It consists of a horizontal rotor made up of 10 vertical flanges spaced 254 mm apart along a horizontal tube, and welded to the tube so that each one rotates 30° from the previous one to form the rotor scroll. A series of short shank "L" shaped blades, three of each hand are bolted around the periphery of each flange to form a rotor diameter of 500 mm. Drive from the tractor pto to the blades is transmitted via a telescopic drive, shaft, over-load clutch unit, bevel-gearbox jackshaft and chain side drive. The gears in the back of the gearbox can be interchanged to provide rotor speeds in the range 190-260 rev/min. Rear trailing boards are hinged behind the main hood of the machine and can be adjusted to determine the flow of soil from the rear of the rotor. The rotor speed used at both sites was 240 re/min.

Land-Packer/Furrow Press - Cousins

This is a 3.05 m wide trailed machine weighing approximately 3478 kg giving 232 kg/ring being spaced at 178 mm centres. A main chassis frame supports three axles each running in two roller bearings. The centre section is designed so that the gap for the bearings coincides with the position of the tractor wheels. Fifteen of 915 mm diameter rings are mounted on the three axles with additional spacing washers. The gap between the rings is kept clean by chains hanging between the front and rear cross members underneath the axle.

Fahr Centipede - Straw Spreader

This is a 4 m wide trailed machine consisting of four star shaped rotors on 1 m centres with six arms on each rotor 540 mm long. Two finger tines are mounted on the end of each arm 380 mm long and tines from adjoining rotors are intermeshed midway between each other. Power is transmitted from the tractor pto via a single speed bevel gearbox to drive the rotors so that the two LH rotors are rotating clockwise and the two RH anticlockwise in order to spread the straw across its width. Castors wheel are mounted underneath the head of each rotor and flexibility between the rotating heads ensures each section can follow the ground contours. The angle of the star shaped rotors can be adjusted to control the spread pattern from the rear of the machine.

Tractor Mounted - Straw Chopper Brown's

This is a fully mounted machine with a cutting width of 2.30 m (2.364 m rotor length) weighing approximately 660 kg. It consists of a horizontal rotor with blade mounting lugs welded around the circumference of a tube, each lug carries a left and right hand "C" shaped universal blade which is free to rotate around a pin. The blades are mounted so that the shank is 90° from the rotor tube. Centrifugal force extends the cutting blades to the radial position when the machine is in work. Fixed static serrated blades are mounted in the 4 o'clock and 2 o'clock positions in front of the main rotor to further fragment the residue as the moving blades pass them. The front half of the rotor is covered with a fixed hood and the top rear portion has an adjustable hood which can be closed to retain material or opened up and fitted with deflectors to spread the chopped residue leaving the rotor. Depth wheels are fitted behind the rotor at both sides of the machine.

Drive is transmitted via the pto of the tractor through a telescopic shaft, bevel gearbox and jackshaft to a four "V" belt final side drive to the rotor. The pto speed of 540 rev/min gives a roto speed of 2000 rev/min. The universal blades can be changed to either two straight blades or four mounted within the same lugs on the rotor. The static serrated blades can also be changed for straight knife type blades in the same two positions on the hood.

Additional machinery in 1993

Tractor Mounted Straw Chopper (Kverneland)

The construction of this machine is very similar to the Brown's machine already described with the exception of the type of cutting blade. Each blade support lug carries two straight double edged blades, and one fan plate which are free to rotate around a pin. Centrifugal force extends the cutting blades which rotate at 2080 rev/min to the radial position. These blades intermesh with fixed knives mounted in the 3 o'clock and 1 o'clock positions in front of the main rotor. The fan plates increase the suction force under the main rotor which assists the flow of straw into the chopping mechanism. Caster type wheels are mounted behind the main rotor with lateral adjustment across the full width of the machine. The machine weighs 890 kg and has a cutting width of 2.55 m.

Plough 30/44

Dowdeswell 120 series Delta-Furra 4+1 Furrow fully mounted reversible mouldboard with 1.12 m point to point spacing and 760 mm underbeam clearance and fitted with S.C.N. mouldboards. Mechanical furrow width adjustment from 300-450 mm to maximise workrate and tractor power for different soil conditions. Large adjustable wrap-round (WR) skim coulters are mounted in front of each plough body or alternatively trashboards can be fitted to the top of each skim. Both devices skim off the edge of each furrow slice and direct the residue into the bottom of the furrow to be buried by soil flowing off the mouldboard. An adjustable depth control wheel is fitted towards the rear of the main frame which can also be use to transport the plough on the road. Total weight is approximately 1700 kg and working width used with 4 furrows was 1.63 m.

Mixing cultivator (Cousins-Wing Z)

This machine is fitted with two rows of rigid tines with twisted shares and wings mounted on a hollow section chassis frame with tractor three-point linkage connections. The tines are spaced laterally at 1000 mm with tine bar spacing and underbeam clearance of 800 mm. At the rear a 460 mm diameter spiroller coil with 140 mm diameter centre tube is supported on adjustable trailing arms to provide a means of depth control and consolidate the straw/soil mix. The scroll of the coil is left and right handed to reduce side forces which assists in the stable operation of the machine. The interaction between the tines produces a boiling effect which aids the straw /soil mix with clean soil flowing from the top of the twisted share to help burial. This machine is also very effective in lifting straw from the base of the carrot bed wheelways. Total weight of the machine is approximately 1050 kg and working width 3.0 m.

Mixing Cultivator (Cousins - Strawboy)

The main frame construction is very similar to the Wing Z cultivator previously described with a 460 mm diameter spiroller coil supported on adjustable arms at the rear. The three rows of 30 mm square double coil spring tines are fitted with twisted shares and spaced laterally at 900 mm with tine bar spacing 750 mm and underbeam clearance of 710 mm. The twisted share deposits clean soil onto the straw residue and the interaction between the tines produces a mix of the straw and soil which is consolidated by the rear coil. This coil also gives an accurate means of depth control. Total weight of the machine is 730 kg and working width 3.0 m.

Rototiller R.V.L. (Rau/Ferrag)

A power take off driven machine consisting of a horizontal axle rotor with wedge shaped tines mounted tangentially to provide a rotor diameter of 500 mm and "pick like" entry into the soil surface. The tines are mounted on a number of spirals to provide an equal spacing of 52 mm around the rotor periphery. Drive from the tractor pto is taken via a bevel gearbox with a four speed change over gear unit through a horizontal jackshaft and chain side drive to the main rotor. Adjustable feeder discs move the soil in front of the rotor bearing supports to give a working depth of 200 mm. The action of the wedge shaped tines rotating vertically in the direction travel mulches in the straw residue across the working width of 3.0 m. The adjustable rear tailgate directs the soil/straw mix down in front of the toothed packer-roller to be consolidated by it. The packer-roller also provides overall depth control. Total weight is 1411 kg and the rotor speed used was 234 rev/min.

Rotalabour FI H. R.40 (Howard)

This is a power take off driven horizontal rotor machine with forged double blade supports welded to the centre tube to form four spirals when viewed from the end of the rotor. Each support contains a left and right handed twisted radial blade to produce a rotor diameter of 610 mm. Drive from the tractor p.t.o is transmitted in a similar manner to that on the Rototiller except the rotor speeds are adjusted by changing the gearbox pick-off gears. A two piece trailing board hinged to the rear of the main hood controls the rearwards flow of the straw/soil mix. Depth control is provided by wheels mounted on adjustable trailing arms attached to both ends of the machine. A open barred crumbler or packer roll can be fitted across the full width in place of the depth wheels. The action of the twisted radial blades rotating in the direction of travel at 260 rev/min mulches in the straw residue. The total weight is 1260 kg for the 3 m wide machine used.

Appendix III: Future modifications to existing machinery

1. Mouldboard plough - improvements to underbeam clearance, point-to-point clearance and improved trashboard design could overcome the blockage problem where there are few pre-mixing cultivations. This has been achieved in the form of the Dowdeswell Delta 120 plough with 30 in (760 mm) underbeam 44 in (1.12 m) interbody clearance.

2. Square plough - improvements to spacing of bodies, change of beam angle, longer legs to improve flow characteristics will enable the tool to cope with reduced pre-mixing cultivations.

3. Mixaplough - modification of vertical disc support brackets to prevent interference with soil/residue flow between bodies.

4. Straw chopping - this is the favoured direction of cultivation developments. The straw would be chopped to lengths 80 to 100 mm long. These small lengths of straw could then be mixed thoroughly into the surface soil, after which inversion would be relatively simple. Although the purchase and operation of a straw chopper would be an additional expense, this could be offset by the need for much reduced pre-mixing cultivations. The straw chopper would need to deal with dry, wet and frozen straw, and be able to extract it efficiently from both on the bed and from the wheelways. The chopped material would then need to be moved away from the bed and spread evenly.

5. Timing of straw chopping - chopping straw off the carrot bed appears to be the most effective way of treating all the straw. However, if a polythene sheet lays below the straw depth of rotor would be critical. Moving already-chopped straw to the side to be subsequently wheeled into the soil surface should also reduce pre-mixing cultivations or even make them unnecessary.