PROJECT REPORT No. 311

EFFECTS OF ESTABLISHMENT TECHNIQUE AND NUMBER OF MANAGEMENT PASSES ON WINTER WHEAT PRODUCTION COSTS

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by

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With contributions from IACR Long-Ashton Research Station

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Contents

Abstract

A 4-year study was undertaken with the aim of reducing the unit costs of consecutive wheat crop production without reducing output, by focusing on the interactions between lower-cost establishment and minimum pass husbandry. Replicated large block trials were conducted in fields at Andover (light chalkland soil), Cirencester (medium loam soil) and Biggleswade (heavy chalky clay loam), starting in autumn 1998 as second wheats and progressing to fourth or fifth wheats. Variables examined were establishment method (direct sowing, minimal tillage and ploughing, all in the presence of chopped straw, and all sown with the same cultivation drill), use of a take-all seed treatment (silthiofam), and number of in-crop husbandry passes. The input strategies varied slightly, but essentially compared two 'minimum' pass systems (3 and 4 core passes) with a control treatment (7 core passes), for application of nitrogen fertiliser and crop protection spray inputs.

On the chalkland soil, minimal tillage gave the highest yields and margins in all years. On the medium loam, ploughing gave the highest yield in 2001, but overall differences were small and direct sowing was the most cost-effective. No single technique was consistently best on the heavy chalky clay loam, but direct sowing was lower yielding in the second and third years, and minimal tillage gave the highest average margin over the three seasons. Direct sowing had the lowest energy cost of establishment, but gave the lowest plant populations. Minimal tillage had the lowest total energy costs per tonne of grain on both the light and heavy soils. Direct sowing resulted in less broad-leaved weeds than ploughing, but higher blackgrass and brome populations. There was also a lower incidence of eyespot and *Septoria tritici* after direct sowing than after ploughing.

The largest yield response to seed treatment was obtained in 1999, when it reduced take-all incidence by half. Despite having had the highest take-all levels in that first year, direct sowing showed the smallest average yield benefit on the light and medium soils. Reducing the number of input passes from 7 to 3 decreased yields at all sites in 2000. This was associated with inferior disease control, only one fungicide having been applied. There was no disadvantage to minimum pass in 2001, under lower disease pressure. However, with application and establishment costs included, the minimum pass strategies were most cost-effective overall. There were some interactions between establishment method and pass number. After ploughing, the 4-pass (with split nitrogen) was as cost-effective as the 3-pass system, whereas after direct sowing it was no better than the 7-pass. At Biggleswade, the direct-sown blocks benefited more from the 7-pass than the other establishment methods.

In a consecutive wheat crop situation, minimal tillage or direct sowing can deliver yields equal to or higher than ploughing on a range of soil types. The greatest benefit from ploughing is likely to be on medium or heavy soils after a wet autumn, or where grass weeds are a problem. Adopting minimum pass husbandry can improve profitability, when the cost of each pass is taken into account. However, for a single fungicide spray to be effective, correct application timing (at flag leaf) is vital. Lower cost establishment does not dictate that a minimum pass approach will be less successful, and the combined benefits could range from £36 to £120/ha.

Summary

Introduction

With grain prices falling to as low as £55/tonne in 2002, and farm sizes continuing to increase, the impetus for achieving major savings in production costs is clear. Previous work conducted by ARC and funded by HGCA has shown that the number of passes needed to apply fertiliser and crop protection inputs to winter wheat can be decreased, without reducing profitability. Other work has shown the potential for greater utilisation of lower-cost, non-inversion methods of cereal crop establishment, without any adverse effect on yield.

However, whilst both techniques have been used successfully for first wheats after a break, wheat following wheat is potentially more difficult, especially where the straw from the previous crop has been chopped. Having opted for a lower-cost establishment technique, this also then raises the question of what impact this might have on the success of a minimum pass approach to the application of inputs.

This project set out to examine the effects of combining lower-cost establishment methods with minimum pass husbandry, in a consecutive wheat crop situation and in the presence of chopped straw. With any cropping sequence involving second-fifth wheats, take-all is likely to be encountered, so the impact of seed treatment would be important. A key objective was to study longer-term effects of establishment and seed treatment, and this could be achieved by keeping the trials in the same place for the duration of the project. It is also vital that such approaches are evaluated on a range of soil types, including heavy land. In addition to maintaining yield and reducing costs, a further objective was to evaluate the energy requirements of the various systems, and to study their impact on weed populations, disease incidence and soil nitrogen status as the project progressed.

Project Overall Aim

To reduce the unit costs of consecutive wheat crop production without significantly reducing output, through exploitation of the interactions between lower-cost crop establishment methods and minimum pass husbandry.

Methods

Replicated large-block winter wheat trials were established in three fields, at Andover (a light chalkland soil), Cirencester (medium soil, loam over gravel) and Biggleswade (heavy chalky clay loam). The trials started in autumn 1998, and continued in the same place for three seasons (1998/99, 1999/00 and 2000/01). Andover and Cirencester were extended for a fourth year (2001/02). Trials began as second wheats, progressing to third, fourth and (at the two locations) fifth wheat situations. All were sown with Consort at 350 seeds/m^2 in early October, except Biggleswade in 2000/01 when a wet autumn forced a change to Paragon spring wheat.

In the first three seasons, the trials examined three variables:

- Establishment method: plough/press, disc/press, or direct sowing, all sown using a disc cultivation drill. Cultivations and drilling were carried out in the presence of chopped straw residues from the previous wheat crop. Slug pellets were routinely admixed with the seed for all establishment methods, and prior to sowing an application of glyphosate herbicide was made to kill any emerged weeds or cereal volunteers.
- The use of the take-all seed treatment silthiofam (Latitude).
- Number of input passes: two experimental minimum (3 and 4) pass strategies were compared with a multi (7) pass control treatment, for the application of all crop protection and nitrogen fertiliser inputs.

The combination of establishment method, seed treatment and number of passes gave eighteen treatments in all, each replicated three times. In the fourth season pass number was removed, allowing greater replication.

The exact numbers of passes in each trial varied, due to the need for additional early grass weed herbicides, and changes made necessary by the wet autumn of 2000/01. However, the core inputs in the 3, 4 and 7-pass systems were in most cases as shown in the table below.

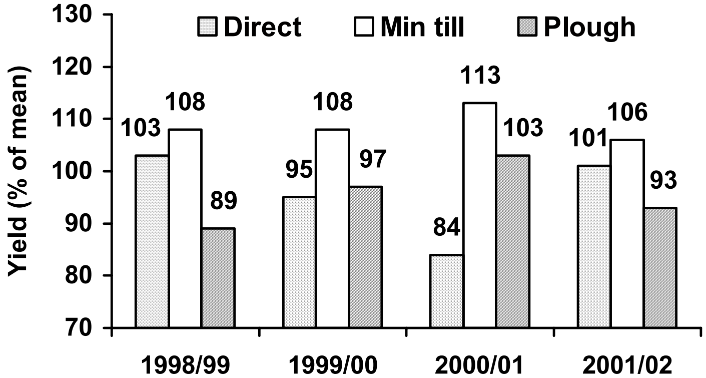
	Pass Systems		
Core Inputs Applied	**'min pass' 3**	**'min pass' 4**	**'control' 7**
Autumn herbicide + insecticide	Yes	yes	yes
First nitrogen dose in early March	no	yes	yes
Main nitrogen dose in early April	yes	yes	yes
Early plant growth regulator at GS30-31	no	no	yes
T1 fungicide at GS32 *	no	no	yes
T2 fungicide at GS39 *	yes	yes	yes
T3 fungicide at GS65 *	no	no	yes

All pass systems received the same total amount of nitrogen, either as a single or split dose. Additional spray inputs (*e.g.* PGR, late herbicide or aphicide) could be included at certain timings (*) without constituting an extra pass. It was therefore only the number of passes that was limited. The fungicides used at each timing varied with site, according to disease pressure, but strobilurins were a key part of each strategy. However, it should be noted that these trials were conducted prior to the discovery of resistant isolates of *Septoria tritici*.

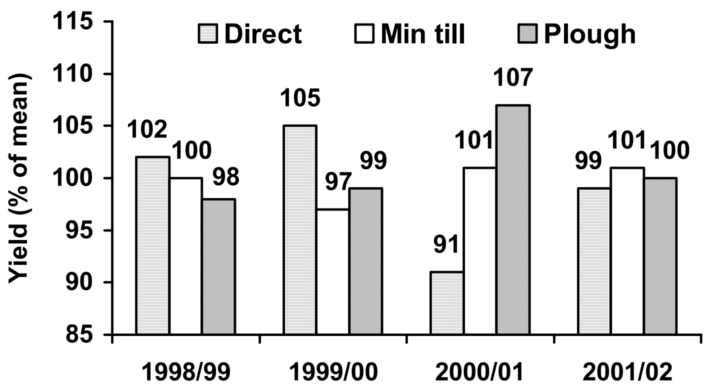
Assessments and monitoring included grain yield and quality, plant and ear populations, soil mineral nitrogen reserves, pest numbers and damage, grass and broad-leaved weed populations, incidence and severity of root take-all, stem base, foliar and ear diseases, and the energy requirements of the establishment techniques and pass systems. Standard costings for cultivations, drilling and input applications, and average prices for the agrochemicals and nitrogen fertiliser used, were used to calculate margins for each treatment. All data was analysed by IACR Long Ashton Research Station.

Results – Establishment Technique

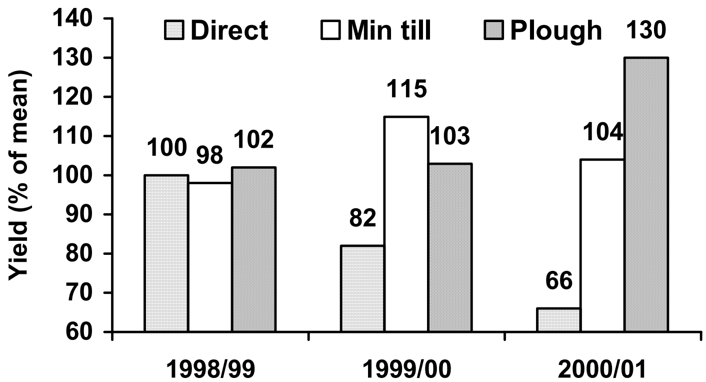
Grain Yield



Andover, light chalkland soil		
Season	Mean Yield (t/ha)	LSD %
1998/99	9.03	6.2
1999/00	7.77	8.4
2000/01	3.92	19
2001/02	8.64	3.1



Cirencester, medium loam soil		
Season	Mean Yield (t/ha)	LSD %
1998/99	8.63	8.5
1999/00	6.91	11.3
2000/01	5.94	13.3
2001/02	7.12	4.9



Biggleswade, heavy chalky clay loam		
Season	Mean Yield (t/ha)	LSD %
1998/99	9.03	9.2
1999/00	6.53	18.5
[illegible]	[illegible]	[illegible]

The effect of establishment technique on grain yield varied between sites. On the light chalkland soil, minimal tillage was highest yielding in all four seasons. At Cirencester, differences were small apart from in 2000/01 when yield was higher after ploughing than after direct sowing. On the heavy soil, direct sowing was lower yielding than minimal tillage or ploughing in all but the first season, when there were no differences.

Margin

Using average input and cultivation costs for the duration of the project, and a feed wheat grain price of £60/t, the margin over costs can be calculated for each establishment method. The following table shows the average margins obtained at each location over the three (or four) years, and the ranking order of performance of each establishment technique in each (harvest) year, 1999, 2000, 2001 and 2002.

Establishment	Andover					Cirencester					Biggleswade			
Method	Margin	Ranking				Margin	Ranking				Margin	Ranking		
	(£/ha)	99	00	01	02	(£/ha)	99	00	01	02	(£/ha)	99	00	01
Direct	175	2	2	3	2	134	1	1	3	1	68	1	3	3
Min till	201	1	1	1	1	115	2	2	2	2	124	3	1	2
Plough	131	3	2	2	3	106	3	3	1	3	117	2	2	1

Overall, minimal tillage was the most cost-effective establishment method on the lightest and heaviest soils. However, relative performance was more consistent at Andover than at Biggleswade. On the medium soil at Cirencester, direct sowing was most profitable, although rankings were reversed in the 2000/01 season.

Energy Costs

The effect of cultivation on the (direct + indirect) energy costs of establishment was calculated for each site, averaged over the first three seasons. These are shown as values per hectare and per tonne of grain output. In all cases, direct sowing had the lowest cost per hectare and per tonne of grain.

Establishment	Andover		Cirencester		Biggleswade	
Method	MJ/ha	MJ/t	MJ/ha	MJ/t	MJ/ha	MJ/t
Direct	690	104	730	102	770	139
Min till	961	128	1280	180	1191	179
Plough	1459	223	1709	237	2826	417

However, when input energy costs were included, minimal tillage had the lowest energy costs per tonne at Andover and Biggleswade.

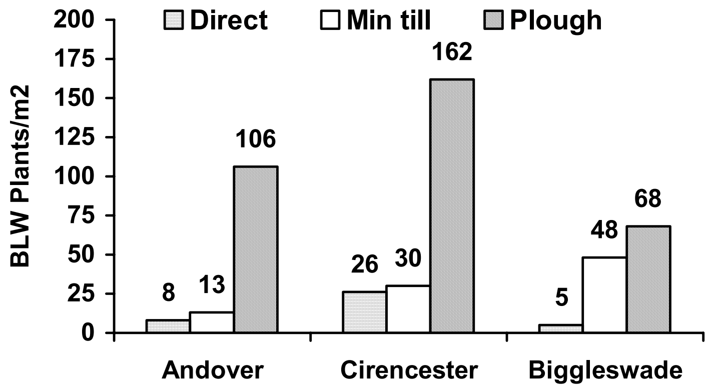
Crop Structure

Direct sowing generally resulted in the lowest plant populations, and ploughing the highest. Largest differences were in autumn 2000, at Andover and Biggleswade. Minimal tillage resulted in significantly fewer plants than ploughing in about half of the trials. Differences in ear populations were often small, and did not necessarily follow the same trends. Average populations for the duration of the project at each location are shown below.

Establishment	Andover		Cirencester		Biggleswade	
Method	Plants/m2	Ears/m2	Plants/m2	Ears/m2	Plants/m2	Ears/m2
Direct	181	377	192	307	159	319
Min Till	223	380	224	308	201	344
Plough	233	343	244	326	221	346

Weed Populations

The biggest effect of establishment technique on broad-leaved weed populations was in the first autumn (1998), with significantly more weeds present (prior to herbicide application) after ploughing.

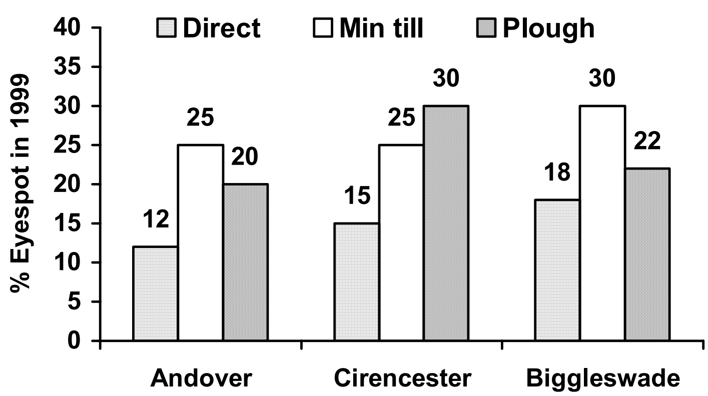


Broad-leaved weeds were well controlled by herbicide programmes at each site, but grass weeds were more of a problem. RRR Resistant blackgrass was present at Cirencester, and brome grass species at Biggleswade. Only in the latter case did establishment have a

Location	Grass weed	Year	Direct	Min till	Plough
			relative grass weed populations		
Cirencester	blackgrass	2001	73.5	52.2	46.8
Biggleswade	brome species	2000	41.7	8.8	0.1

Disease Incidence

At all sites in 1999 the incidence of eyespot was lowest after direct sowing. In 2002 eyespot severity was significantly lower after direct sowing than after ploughing at both Andover and Cirencester.



The only foliar disease present in all trials was *Septoria tritici*. In almost all cases, incidence was significantly lower following direct sowing than after ploughing. Sometimes, differences were still apparent in July.

Establishment Method	Andover	**April 1999** Cirencester	Biggleswade	**May 2000** Cirencester	**July 2000** Biggleswade
		Disease leaf area (*Septoria tritici*)			
Direct	16.7	17.7	12.2	8.9	16.8
Min till	22.5	21.3	15.9	9.4	21.3
Plough	22.5	22.5	15.1	10.9	25.6
LSD	3.7	2.6	2.9	1.0	4.3

Effect of Latitude Seed Treatment, and Interaction with Establishment Method

Grain Yield

Largest yield responses to the Latitude seed treatment were obtained in the first season (second wheat). Smaller benefits were observed in 1999/00 (third wheat), but there were no significant increases thereafter.

Yield response to Latitude	Andover 1998/99	Andover 1999/00	Cirencester 1998/99	Biggleswade 1998/99	Biggleswade 1999/00
%	10	4	4	12	4
t/ha	0.86	0.32	0.36	0.99	0.26
LSD (t/ha)	0.16	0.28	0.28	0.24	0.15

Averaged over all seasons, at Andover the take-all seed treatment gave most benefit in the ploughed situation. At Cirencester, minimal tillage showed the largest response. At Biggleswade, all three methods were similar.

Establishment Method	% Yield Response to Latitude		
	Andover	**Cirencester**	**Biggleswade**
Direct	3.4	0.6	7.1
Min till	3.7	5.9	6.2
Plough	6.3	1.0	7.2

Margin

In the first season, where the use of Latitude was most beneficial, direct sowing at Cirencester was the only situation where the yield response was not sufficient to at least cover the cost of the seed treatment. It was cost effective for all establishment methods at Andover and Biggleswade.

Establishment Method	Increase (+) or Decrease (-) in Margin (£/ha) with Latitude		
	Andover	**Cirencester**	**Biggleswade**
Direct	+24	-28	+17
Min till	+19	+13	+39
Plough	+33	0	+40

Take-all Incidence

The decrease in take-all incidence resulting from the use of the seed treatment was typically about two-thirds in November of the first year. By February, this decrease had been reduced to half, and although differences between establishment methods were small, direct sowing tended to have the highest levels.

Establishment Method	Andover Sibutol	Andover + Latitude	Cirencester Sibutol	Cirencester + Latitude	Biggleswade Sibutol	Biggleswade + Latitude
	Take-all Incidence (%) in February 1999					
Direct	97	47	93	57	97	53
Min till	80	40	70	37	97	40
Plough	83	37	97	37	83	50

Effect of Number of Husbandry Passes, and Interaction with Establishment Method

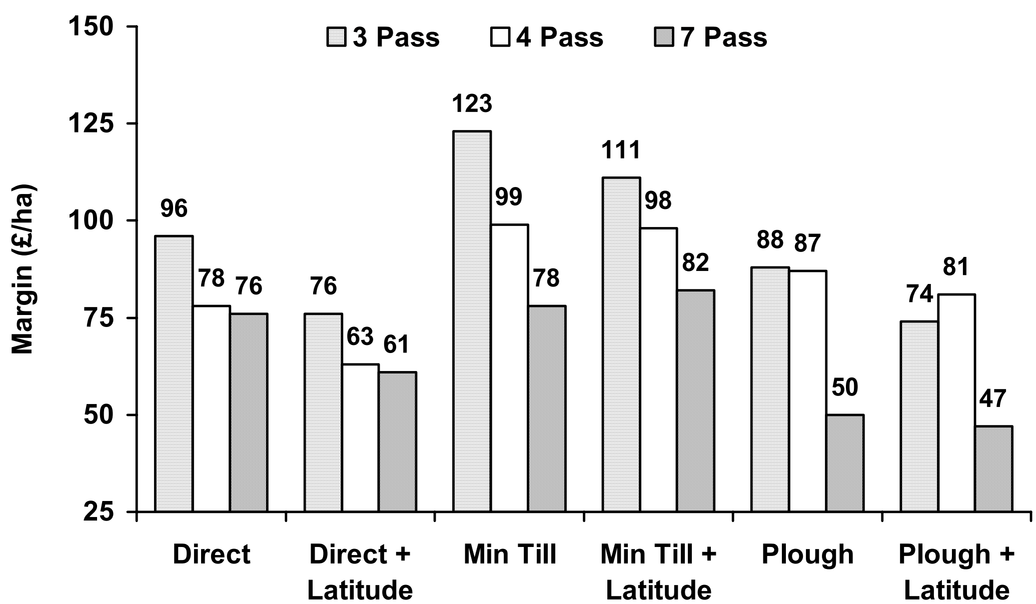
Grain Yield and Quality

At Andover and Cirencester, reducing the number of input passes from 7 to 3 decreased yields in both 1999 and 2000. Specific weight was also reduced, typically by 1-2 kg/hl. In 2001, there was no disadvantage to the minimum pass systems. At Biggleswade the only significant yield penalty with minimum pass was in 2000. There was no overall advantage to the 4-pass system (with a split nitrogen dose) compared to the 3-pass:

Husbandry Pass System	Andover			Cirencester			Biggleswade		
	1999	2000	2001	1999	2000	2001	1999	2000	2001
	Yield (% of trial mean)								
3 (min pass)	97	99	103	95	97	100	100	92	99
4 (min pass)	98	97	103	96	94	103	98	93	96
7 (control)	105	104	94	110	110	97	102	115	105
LSD %	4.4	3.6	21.4	6.3	4.3	8.8	10.5	20.2	24.6

Margin after Costs

Although the 7-pass control treatment gave the highest yields in most trials, differences in gross margin were relatively small. When application and establishment costs were included it was the minimum pass strategies that were the most profitable for all sites. The only exception to this was after direct sowing at Biggleswade, when 7 passes was more cost-effective. The graph below shows the combined effects of establishment method, seed treatment and number of input passes on profitability (£/ha), after deduction of establishment, application and input costs. The margins shown are averages over the three sites, and over the three seasons.



After ploughing, the 4-pass strategy, which included a split nitrogen dose, was as cost-effective as the 3-pass (which did not). In contrast, with direct sowing the 4-pass was no more cost-effective than the 7-pass control.

Disease Control

The main factor that influenced whether a yield penalty resulted from the minimum pass strategies compared to the 7-pass treatment was the control of foliar disease. At Andover and Cirencester, there was significantly less *Septoria tritici* on the upper leaves in the 7-pass system than in the 3 or 4 pass systems in both 1999 and 2000. In 2001, when there was no yield penalty, there were no differences between pass systems.

Separate small plot trials were conducted in 1999, 2000 and 2001 to investigate the most appropriate timings for the application of a single fungicide treatment within a minimum pass strategy. Single sprays based on full and half-rate doses of strobilurins with triazole were evaluated at three timings, GS32, GS37 and GS39-45, compared to a normal 3-spray programme with applications at GS32, GS39 and GS65. Trials were conducted on the same variety, Consort, at Andover and Biggleswade, and were taken to yield.

Grain Yield - % of 3-spray control

			Andover			**Biggleswade**	
		1999	**2000**	**2001**	**1999**	**2000**	**2001**
GS32	Amistar 0.5 + Opus	99	77	100	96	78	97
	Amistar 1.0 + Opus	94	81	98	93	77	98
GS37	Amistar 0.5 + Opus	94	77	101	93	87	99
	Amistar 1.0 + Opus	97	82	101	97	90	97
GS39-45	Amistar 0.5 + Opus	97	93	99	93	79	100
	Amistar 1.0 + Opus	95	96	99	98	85	100
Control yield (t/ha) 100 % =		7.56	9.61	9.09	9.20	9.38	9.78
	LSD (%)	6.6	5.1	4.5	7.0	5.7	3.4

Disease Control - % *S. tritici* (*plus brown rust) on leaf 2

			Andover			**Biggleswade**	
		1999	**2000**	**2001**	**1999**	**2000***	**2001**
GS32	Amistar 0.5 + Opus	78	32	5.5	24	15	3.9
	Amistar 1.0 + Opus	83	17	6.8	12	12	2.2
GS37	Amistar 0.5 + Opus	19	29	2.5	10	30	5.5
	Amistar 1.0 + Opus	27	17	1.3	4	6	4.0
GS39-45	Amistar 0.5 + Opus	45	27	1.2	10	27	6.2
	Amistar 1.0 + Opus	34	10	2.0	7	12	7.8
3-Spray Control		12	2.0	1.5	0.7	4.2	1.0

Yield penalties from single-spray treatments were highest in 2000 and lowest in 2001. Under high disease pressure in 2000, the only single-spray not to give a significant penalty at Andover was full dose at GS39-45. At Biggleswade, GS37 was the optimum. Higher dose rates did not compensate for incorrect timing. With less disease in 2001, there were no differences between single-spray dose rates or timings, and the 3-spray control.

Conclusions and Implications

This project demonstrated that, in a consecutive wheat crop situation and in the presence of chopped straw residues, minimal tillage and direct sowing are capable of delivering equal or higher crop yields than a conventional plough-based approach, on light, medium and heavy soils.

On the light chalkland soil at Andover, minimal tillage was the most profitable establishment method in all four seasons, averaging £26/ha more margin than direct, and £70/ha more than ploughing.

On the medium loam soil at Cirencester, direct sowing was more cost-effective than the other methods in three out of four seasons, averaging £19/ha more profit than minimal tillage and £28/ha more than ploughing.

On the heavy clay at Biggleswade, no single technique was best in all seasons. Direct sowing was the most cost-effective in the first year, minimal tillage in the second and ploughing in the third. Direct performed poorly after the first year, averaging £49/ha less margin than ploughing and £56/ha less than minimal tillage.

The greatest advantage to ploughing was on the medium and heavy soils in 2000/01, when, as a result of the unusually wet autumn, the direct-sown blocks established poorly. With the exception of Andover, grass weeds quickly emerged as limiting factors at Cirencester (resistant blackgrass) and at Biggleswade (brome grasses). This contributed to the problems encountered after direct sowing, with ploughing the most effective method of brome control at Biggleswade. On chalkland soils with no difficult grass weeds, minimal tillage should provide a sustainable basis for reducing establishment costs for consecutive wheat crops. However, a more flexible approach is needed on medium or heavy soils, where very wet soil conditions under chopped straw may reduce the success of non-inversion methods. Difficult-to-control grass weeds are likely to compound this problem.

There was little indication that minimal tillage or direct sowing increase the risk of take-all, or likelihood of a response to a seed treatment, even in the presence of chopped straw. As the project progressed, highest take-all severity often occurred after ploughing. None of the establishment methods showed sustainable benefits from the seed treatment after the first year. There was evidence of lower incidences of eyespot and *Septoria tritici* after direct sowing, than after ploughing. Minimal tillage also sometimes showed an advantage over ploughing. In some, but not all, cases these differences could partly have been attributable to differences in crop density.

In two out of three seasons, the 3 and 4 'minimum' pass husbandry strategies gave yield reductions compared to the 7-pass control. The penalties were associated with higher levels of disease. In 2001, when disease pressure was low and yields were restricted by the wet autumn, there was no advantage to the higher number of passes. However, in many cases the savings in chemical and applications costs were greater than the reduction in output. Overall the lowest number of passes was the most cost-effective strategy for all sites.

The average increase in margin as a result of adopting a minimum pass approach was £46/ha at Andover, £21/ha at Cirencester and £20/ha at Biggleswade. One reason for the greater benefit at Andover compared to the other locations was the smaller yield difference between husbandry strategies in 2000. The minimum pass fungicide experiments indicated that this was due to a smaller penalty resulting from a single fungicide spray.

A succession of wet, high disease pressure seasons could therefore radically alter the relative economics of low and high pass systems. Correct application timing is vital for a single spray to be effective, particularly under high disease pressure. The results obtained in this project confirm that this is most likely to be during, or just after, flag leaf emergence, in order to maximise protection of the top two leaves. Whatever the timing, single sprays are unlikely to be substantially more profitable than a multi-spray programme, and may be much less profitable in high disease pressure seasons. A single pass strategy is also more likely to be cost-effective where each pass is considered to have a direct cost attached, rather than the saving in agrochemical cost alone.

These trials were conducted on the highly susceptible variety Consort, to provide the sternest possible test. In practice, the risk should be minimised by only using the approach on varieties with good disease resistance. Flexibility to increase the dose rate or if possible revert to a multi-spray programme would be important.

Overall there was little benefit from splitting the nitrogen dose, which was the difference between the 3 and 4 pass strategies, suggesting that this pass could readily be omitted even in non-first wheats. However, in these trials the timing of the main dose of nitrogen was brought forward to reduce the risk of uptake decreasing as take-all damage to the roots increased. There was still a benefit in some of the ploughed situations, but this was not due to differences in soil mineral nitrogen, which if anything were lowest after minimal tillage. In a farm situation, it may also be undesirable to try to apply all of the nitrogen to a crop in one large dose.

A key objective of this project was to establish whether adopting a lower cost establishment method affected the success of minimum pass husbandry. There was only one circumstance where this was the case, which was on the heavy clay soil at Biggleswade. Here the poorly established direct-sown blocks appeared to benefit more from the highest number of passes. Indeed the lower disease pressure and lack of benefit from split nitrogen seen with the non-inversion methods should facilitate a minimum pass approach. The combination of minimal tillage and minimum pass husbandry improved overall margin by an average of £120/ha on the light chalkland soil at Andover, and £52/ha on the heavy clay at Biggleswade. On the medium loam at Cirencester, the best combination of direct sowing and minimum pass gave a more modest improvement of £36/ha.

Effects of Establishment Technique and Number of Management Passes on Winter Wheat Production Costs

1. Introduction

With cereal grain prices falling to as low as £55/tonne in 2002, the impetus for reducing their unit costs of production has never been greater. Simple reductions in expenditure on inputs alone are unlikely to achieve savings of sufficient magnitude, and therefore 'fixed' costs must be also be addressed, in particular the cost of establishing the crop and then applying the necessary inputs. With farm sizes increasing, and winter wheat increasingly dominant in rotations, the need to save time can be as important as the need to save money. Once again, the autumn establishment and spring husbandry periods are fundamental to achieving this.

Previous work funded by the Home-Grown Cereals Authority and conducted by Arable Research Centres in 1994-1997 (Project Report 167) has shown that the number of passes needed to apply fertiliser and crop protection inputs to winter wheat can be decreased, without reducing profitability. Other work has shown the potential for greater use of lower-cost, non-inversion methods of crop establishment, without any adverse effect on yield. Whilst both techniques have been used successfully for first wheats after a break, wheat following wheat is potentially more difficult, especially where the straw from the previous crop has been chopped. Having opted for a lower-cost establishment method, this also then raises the question of what impact this might have on the success of a minimum pass approach to the application of inputs.

This project set out to examine the effects of combining lower-cost establishment methods with minimum pass husbandry, in a consecutive wheat crop situation and in the presence of chopped straw. With any cropping sequence involving second through to fifth wheats, take-all is likely to be encountered, so the impact of seed treatment would be important. A key objective was to study the longer-term effects of establishment method and seed treatment, and this could be achieved by keeping the trials in the same place for the duration of the project. It is also important that the approaches are evaluated on a range of soil types, including on heavy land where non-inversion establishment might be considered less suitable for consecutive wheat crops.

In addition to maintaining yield and reducing costs, a priority was to evaluate the energy requirements of the various systems, and to examine their cumulative impact on weed populations, soil nitrogen and disease levels. Fungicide sprays account for at least three passes in an average wheat crop, so a separate study was initiated to examine the role of strobilurins in the development of an effective minimum pass disease control strategy.

Project Overall Aim

To reduce the unit costs of consecutive wheat crop production without significantly reducing output, through exploitation of the interactions between lower-cost crop establishment methods and minimum pass husbandry.

2. Materials and Methods

2.1 Overview

Replicated large-block winter wheat trials were established in three fields, at Andover (a light chalkland soil), Cirencester (medium soil, loam over gravel) and Biggleswade (a heavy chalky clay loam). The trials were started in autumn 1998, and continued in the same place for three seasons (1998/99, 1999/00 and 2000/01). Andover and Cirencester were subsequently extended for a fourth year (2001/02). All trials started as second wheats, progressing to third, fourth and (at Andover and Cirencester) fifth wheat situations. However the exceptionally wet autumn of 2000 meant that in the third season at Biggleswade it was not possible to drill the wheat crop until spring 2001. In the first three seasons, the trials examined three variables:

- Establishment method: plough/press, disc/press, or direct sowing, all sown using a disc cultivation drill. Cultivations and drilling were carried out in the presence of the chopped straw residues from the previous wheat crop.
- Seed treatment: the effect of using a take-all treatment (in addition to a basic seed treatment) was compared with the basic treatment alone
- Number of input passes: two experimental 'minimum' (3 and 4) pass husbandry systems were compared with a multi (7) pass control treatment, for the application of all in-crop herbicide, insecticide, fungicide and plant growth regulator sprays, and nitrogen fertiliser inputs.

The three husbandry pass systems were superimposed on the two seed treatment alternatives, which in turn were superimposed on the three establishment methods, to give eighteen treatments, each replicated three times. In the fourth season, the pass number variable was removed, so each combination of establishment method and seed treatment was replicated nine times.

2.2 Site Locations, Soil Types and Cropping Histories

Site characteristics for the three locations were:

Andover, Hampshire	Soil type Andover series chalkland soil	
	Average annual rainfall 735 mm	
	Previous crop	1997/98 winter wheat
		1996/97 winter oats
Cirencester, Gloucestershire	Soil type Badsey 2 series calcareous loam over gravel	
	Average annual rainfall 770 mm	
	Previous crop	1997/98 winter wheat
		1996/97 spring barley

Biggleswade, Bedfordshire	Soil type Cannamore series calcareous clay / clay loam	
	Average annual rainfall 570 mm	
	Previous crop	1997/98 winter wheat
		1996/97 set-aside

2.3 Varieties, Sowing Dates and Seed Rates

All trials were sown with the winter wheat variety Consort, except the trial at Biggleswade in 2000/01 which was sown with the spring wheat variety Paragon. Sowing dates for the winter wheats were all within the target window of early-mid October, but the spring wheat could not be sown until mid-May. The seed rate used throughout was 350 seeds/m^2, and methiocarb slug-pellets (5.5 kg/ha Draza) were routinely admixed with the seed for all establishment methods.

2.4 Establishment Techniques

Plough and press. Blocks were ploughed in early September, and either pressed at the same time as ploughing, or (at Biggleswade only) as a separate operation.
Disc and press. Blocks were disced and pressed once in early September to a depth of about 3-4 inches.
Both cultivation methods were carried out using equipment already present on the host farm.
Direct sowing. In these blocks, no prior cultivations were carried out, other than that achieved with the drill.

Prior to sowing in the autumn, either all blocks (at Cirencester and Biggleswade), or just the minimal tillage and direct-sown (at Andover), received an application of glyphosate herbicide to kill any emerged weeds or cereal volunteers. At Biggleswade in 2000/01, paraquat was applied to all blocks in the spring prior to sowing.
The drill used to sow all establishment blocks, including the ‘direct-sown’, was a Vaderstad Rapid cultivation disc drill (with the front-mounted discs in work). In all cases, rolling (with Cambridge rolls) followed drilling.

2.5 Seed Treatments

The two seed treatment alternatives compared were as follows:
Sibutol (375 g/l bitertanol + 23 g/l fuberidazole). Application rate 150ml per 100 kg seed.
This was intended to control routine seed borne diseases such as Fusarium and bunt.
Sibutol plus Latitude (125 g/l silthiofam). Latitude application rate 200ml per 100 kg seed.
Latitude was added with the intention of providing (partial) control of take-all
A single untreated seed stock was used, half of which was treated with Sibutol plus Latitude, and the other half with Latitude only.

2.6 Input Pass Systems

In 2001/02, number of input passes was not examined, so the two sites received an unrestricted number of passes according to normal practice and the individual site requirements. The three husbandry pass systems that were evaluated in the first three seasons of the project are outlined in Table 2.1.

Table 2.1 Outline of core treatments applied within each pass system

Core Inputs Applied	Pass Systems		
	'min pass' 3	**'min pass' 4**	**'control' 7**
Autumn herbicide + insecticide	yes	yes	yes
First nitrogen dose in early March	no	yes	yes
Main nitrogen dose in early April	yes	yes	yes
Early plant growth regulator at GS30-31	no	no	yes
T1 fungicide at GS32 (plus herbicide)*	no	no	yes
T2 fungicide at GS39 (plus PGR or herbicide)*	yes	yes	yes
T3 fungicide at GS65 (plus aphicide)*	no	no	yes

* Optional additional inputs that could be included in those passes if needed

The exact number of passes that constituted the two minimum pass systems and the multi pass control varied from site to site and from season to season. This was mainly due to the need to apply one or more additional herbicides where grass weeds were a problem, or as a result of changes made necessary by the adverse autumn conditions in the 2000/01 season. However, the '4' pass system always had one more pass than the '3' pass (which was an early application of nitrogen). The multi (7) pass control had between one and three more passes than the '4' pass (in most cases, additional fungicides at T1 and T3, and an early application of plant growth regulator). Base applications of P and K fertilisers were ignored for the purposes of these experiments. All inputs were applied using a 12m wide conventional farm sprayer or 12m pneumatic fertiliser spreader.

As stated above, the actual herbicide treatments applied varied from site to site and from season to season, according to the weed species present and the time of application. Additional pre-emergence and/or spring herbicides were applied in 1999/00 and 2000/01 for the control of resistant blackgrass at Cirencester, and in 1999/00 for high populations of brome grasses at Biggleswade.

Nitrogen fertiliser doses also varied from site to site, according to soil type and likely yield optimum, but were typically about 200 kg N/ha. The total amounts applied were always the same for all three of the pass systems, with either the whole dose applied in early-mid April (3 pass), or with 20-40% applied earlier (4 and 7 pass).

The GS30-31 plant growth regulator that was applied only to the 7-pass control treatment was 5C Cycocel (645 g/l chlormequat + choline chloride). This input was omitted from Andover (due to poor growth) and Biggleswade (due to late spring sowing) in 2000/01. In the same season, Andover had an extra post-emergence application of methiocarb slug pellets on all treatments, and Cirencester had an insecticide (chlorpyrifos) applied to all pass systems to control wheat orange blossom midge. Fungicide products and doses varied from site to site, according to local disease pressure. However, the most common treatments at each stage were:

T1 (GS32)	0.5 l/ha Opus (125 g/l epoxiconazole) + 0.5 l/ha Bravo (500 g/l chlorothalonil)
T2 (GS39)	0.75 l/ha Amistar (250 g/l azoxystrobin) + 0.25-0.5 l/ha Opus
T3 (GS59)	0.25-0.5 l/ha Amistar

For the spring sown wheat at Biggleswade in 2000/01, only two fungicide treatments (both based on Amistar 0.25 l/ha + Folicur 0.25 l/ha) were appropriate, and therefore in that season the multi pass control treatment only consisted of 5 passes.

These trials were conducted prior to the discovery of strobilurin-resistant isolates of *Septoria tritici*. The treatments that were included were not intended to, and therefore do not necessarily, represent best current practice for the effective use of strobilurins or for the control of *S. tritici*.

Excepting the additional passes made necessary by problem grass weeds and by adverse conditions in the 2000/01 season, the main restriction that applied for each husbandry system was number of passes, and not the number of inputs that might be applied during each pass. Therefore within the protocol it was permitted to apply additional inputs if required, provided that they were compatible with an existing pass through the crop. For example, if there was a high lodging risk, a late PGR could be tank-mixed with the T2 fungicide at GS39, and this would have been applied to all pass systems. Late herbicides could be included with either the T1 fungicide (for the 7-pass control only) or the T2 fungicide (for all pass systems). If aphids had been present, an aphicide could be added to the T3 fungicide, but this would only have been applied to the 7-pass control.

Full lists of inputs applied to each of the trials in 1998/99, 1999/00 and 2000/01 are shown in appendix A, Tables 7.1-7.9.

2.7 Trial Design

Cultivations were carried out in blocks measuring 12m wide and 72m long (main plots), each replicated three times across the width of the field. At drilling these were subdivided into two 6m wide strips, half of which was sown with Sibutol treated seed, and half with Sibutol plus Latitude (sub plots). The strips were then divided into three 24m lengths. In the first three seasons, these were managed with the three different pass systems (sub sub plots), giving three replicates for each combination. In the final season, these were used to create extra replication, giving nine replicates. In both cases the effective plot size was therefore 144m^2.

2.8 Assessments and Data Analysis

The assessments and monitoring conducted during the first three seasons consisted of:

- Grain yield, specific weight, thousand grain weight and, at Andover only, protein content and Hagberg Falling Number
- Autumn plant populations, and ear populations at harvest
- Soil mineral nitrogen reserves at up to 90cm depth, measured in November, February and post-harvest
- Pest populations and damage (including slugs and aphids)
- Grass and broad-leaved weed populations in autumn, spring and summer
- The incidence and severity of root take-all, stem base, foliar and ear diseases at appropriate timings

In addition, tractor forward speed and horsepower, and implement width, were recorded to allow differential energy requirements of the cultivation techniques and pass systems to be calculated (see appendix B, Tables 7.10-7.12). Standard costings for cultivations, drilling and input applications, and average prices for the agrochemicals and nitrogen fertiliser used, were used to calculate margins for each treatment.

In 2001/02, there was no assessment of grain protein or Hagberg, soil nitrogen, foliar or ear diseases, or energy requirements.

All data was analysed by IACR Long Ashton Research Station using the statistical programme Genstat.

3. Results

The results from the three-trial series over the three or four seasons are divided into the following areas:

3.1 Grain Yield	3.2 Economic analysis	3.3 Energy usage	3.4 Grain Quality
3.5 Crop Structure	3.6 Disease Levels	3.7 Weed Infestation	3.8 Soil Nitrogen

3.1 Grain Yield

3.1.1 Effect of Establishment Method on Grain Yield 1999 - 2002

The effect of establishment method on winter wheat yield varied greatly between sites / soil types over the four years of the project. In contrast, seasonal influence was less pronounced, with the exception of the differences caused by the very wet autumn and winter of 2000/01. The following tables (3.1.1-3.1.3) show the effect of establishment method on yield over the four years of the project, with all other variables (seed treatment and number of passes) averaged.

Table 3.1.1 Effect of establishment on winter wheat yield (t/ha) 1999-2002 Andover, chalkland soil

	Cropping year / rotation position				
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean (t/ha)**
Direct sowing	9.29	7.38	3.31	8.72	**7.18**
Minimal tillage	9.76	8.38	4.41	9.20	**7.94**
Plough and press	8.04	7.54	4.04	7.99	**6.90**
LSD ($p = 0.05$)	0.56	0.65	0.74	0.27	
Sowing date	5th Oct	5th Oct	6th Oct	5th Oct	

In the presence of chopped straw from the previous wheat crop, minimal tillage significantly outyielded ploughing in all years except 2001, when the wet autumn/winter and plot damage reduced overall yields. The difference between minimal tillage and ploughing over the four years averaged 15% (1.04 t/ha). The advantage of minimal tillage over wheat sown directly into the stubble / chopped straw was not as great, with a significant yield difference in only 2 out of the 4 years. The direct method of establishment was superior to the plough blocks in the second and fifth wheat, but performed very poorly in the 2001 season, when the preceding wet autumn reduced establishment levels below the 50-60% level achieved in other years of the project.

Table 3.1.2 Effect of establishment on winter wheat yield (t/ha) 1999-2002 Cirencester, medium loam

		Cropping year / rotation position			
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean (t/ha)**
Direct sowing	8.81	7.24	5.42	7.05	**7.13**
Minimal tillage	8.65	6.68	6.01	7.18	**7.13**
Plough and press	8.44	6.81	6.38	7.14	**7.19**
LSD (p = 0.05)	0.73	0.78	0.79	0.35	
Sowing date	5th Oct	6th Oct	16th Oct	13th Oct	

With the exception of the 2001 season none of the yield differences created by establishment technique were statistically significant. This was reflected in the overall 4-year means, which showed less than 0.1 t/ha yield difference. However as a result of the very wet autumn in 2000, direct sowing produced significantly lower yields than minimal tillage and ploughing. The inferior yields with direct sowing in 2001 appeared to be the result of poorer crop establishment, which as a consequence was less able to compete with the high population of resistant blackgrass at this site.

Table 3.1.3 Effect of establishment on winter wheat yield (t/ha) 1999-2002 Biggleswade, chalky clay loam

		Cropping year / rotation position		
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat (spring-sown)**	**Mean (t/ha)**
Direct sowing	9.02	5.36	2.25	**5.54**
Minimally tillage	8.87	7.50	3.55	**6.64**
Plough and press	9.19	6.73	4.43	**6.78**
LSD (p = 0.05)	0.83	1.21	1.03	
Sowing date	13th Oct	7th Oct	15th May	

Whilst direct sowing performed well in the first year of the project (second wheat), problems occurred in the direct blocks in the second and third seasons, with poor establishment resulting in a lack of competition with the high grass weed population (Brome species) that developed. Thus in the third wheat, and the spring wheat crop established in 2001, direct sowing was significantly lower yielding than the two other techniques.

3.1.2 Effect of Take-all Seed Treatment on Grain Yield 1999 - 2002

The influence of the take-all seed treatment Latitude was evaluated in all years of the project, replicated on the same establishment blocks as the previous years. From the results therefore it is possible to evaluate the value of the seed treatment as the wheat rotation position moved from second to fifth wheat situations. The following data represent the mean yields of all establishment methods and pass systems (1999-2001 only)

Table 3.1.4 The effect of seed treatment on wheat yield (t/ha) 1999-2002 Andover, chalkland soil

		Cropping year / rotation position			
Seed Treatment	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean (t/ha)**
Sibutol	8.60	7.60	3.95	8.55	**7.18**
Sibutol + Latitude	9.46	7.92	3.88	8.71	**7.49**
LSD ($p = 0.05$)	0.16	0.28	0.13		
Yield benefit t/ha	**0.86**	**0.32**	**- 0.07**	**0.16**	**0.31**
	+10%	**+4%**	**-2%**	**+2%**	**+4%**

The advantage to Latitude seed treatment on the chalkland soil was greatest in the second and third wheats, with the yield difference being statistically significant. In the fourth and fifth wheat there was no significant advantage to the use of Latitude seed treatment.

Table 3.1.5 The effect of seed treatment on wheat yield (t/ha) 1999-2002 Cirencester, medium loam

		Cropping year / rotation position			
Seed Treatment	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean (t/ha)**
Sibutol	8.45	6.85	5.91	7.04	**7.06**
Sibutol + Latitude	8.81	6.96	5.95	7.20	**7.23**
LSD ($p = 0.05$)	0.16	0.29	0.45	0.20	
Yield benefit t/ha	**0.36**	**0.11**	**0.04**	**0.16**	**0.17**
	+4%	**+2%**	**+0.5%**	**+2%**	**+2%**

At the slightly heavier site at Cirencester there was a similar overall pattern of response with greater benefit to Latitude in the second wheat situation than in the third to fifth wheat position. Taking the overall level of response to Latitude, it was considerably smaller than that experienced at Andover.

Table 3.1.6 The effect of seed treatment on wheat yield (t/ha) 1999-2002 Biggleswade, chalky clay loam

	Cropping year / rotation position			
Seed Treatment	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat (spring-sown)**	**Mean (t/ha)**
Sibutol	8.53	6.40	3.40	**6.11**
Sibutol + Latitude	9.52	6.66	3.41	**6.53**
LSD (p = 0.05)	0.24	0.15	0.19	
Yield benefit t/ha	**0.99**	**0.26**	**0.01**	**0.42**
	+12%	**+4%**	**0%**	**+7%**

On heavy soil, response to Latitude mirrored results achieved at the lighter chalkland site, with greatest benefit to the take-all seed treatment in the second wheat. Thereafter response declined, though the extremely wet autumn of 2000 forced the autumn sowing to be postponed until the spring.

Over the three sites, despite widely differing soil types the response to Latitude was very similar, with largest responses in the second wheats and no increases in the fourth wheats. However this analysis masks the fact that significant yield responses were achieved in third wheat under specific establishment systems. The interactions between establishment method and seed treatment response are considered in section 3.1.4.

3.1.3 Effect of Minimum Pass Husbandry on Grain Yield 1999 - 2001

The third variable in this experiment was the number of husbandry passes used to apply nitrogen fertiliser and in-crop agrochemical sprays. This element of the project was not included in the 2002 extension year. The two experimental minimum pass systems (3 and 4 core passes) were compared against the control treatment (7 core passes). In the following tables, the effect of number of passes through the crop is shown, with the effects of seed treatment and establishment method averaged.

Table 3.1.7 The effect of number of passes on wheat yield (t/ha) 1999-2001 Andover, chalkland soil

	Cropping year / rotation position			
Husbandry Pass System	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**Mean (t/ha)**
3 (min pass)	8.78	7.67	4.04	**6.83**
4 (min pass)	8.86	7.50	4.03	**6.80**
7 (control)	9.45	8.12	3.68	**7.08**
LSD (p = 0.05)	0.40	0.28	0.84	
Yield difference (t/ha)	**-0.67**	**-0.45**	**+0.36**	
3 versus 7 passes	**-7%**	**-6%**	**+10%**	

With the exception of 2001 where results were affected by the extreme autumn and winter weather, there was a significant yield benefit from managing the crop with the highest number of passes. In the second and third wheat reducing the number of passes from 7 to 3 reduced yield by 0.67 and 0.45 t/ha, however as shown in Table 3.2.7 the yield reductions were frequently not great enough to prevent fewer passes being the more profitable option. The 4-pass system, which involved splitting the total nitrogen into two doses instead of one, showed little if any benefit.

Table 3.1.8 The effect of number of passes on wheat yield (t/ha) 1999-2001 Cirencester, medium loam

		Cropping year / rotation position		
Husbandry Pass System	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**Mean (t/ha)**
3 (min pass)	8.16	6.67	5.87	**6.90**
4 (min pass)	8.25	6.47	6.09	**6.94**
7 (control)	9.48	7.59	5.70	**7.59**
LSD (p = 0.05)	0.54	0.30	0.52	
Yield difference (t/ha)	**-1.32**	**-0.92**	**+0.17**	
3 versus 7 passes	**-14%**	**-12%**	**+3%**	

With the exception of the 2001 season when establishment of all trials was to some degree impaired by the very wet autumn, the yield effect of reducing the number of passes was relatively consistent with a 12-14% reduction. There was no yield advantage from splitting the applied nitrogen rather than applying it as a single dose *i.e.* from the 4-pass system compared to the 3-pass.

Table 3.1.9 The effect of number of passes on wheat yield (t/ha) 1999-2001 Biggleswade, chalky clay loam

		Cropping year / rotation position		
Husbandry Pass System	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat (spring)**	**Mean (t/ha)**
3 (min pass)	9.03	6.02	3.38	**6.14**
4 (min pass)	8.81	6.04	3.27	**6.04**
7 (control)	9.25	7.54	3.58	**6.79**
LSD (p = 0.05)	0.95	1.32	0.84	
Yield difference (t/ha)	**-0.22**	**-1.52**	**-0.20**	
3 versus 7 passes	**-2%**	**-20%**	**-6%**	

At Biggleswade there was a more erratic response to numbers of passes, with yield reductions in every case from adopting fewer passes. However the actual yield reduction varied widely from 2.4% in 1999 to 20.2% in 2000. As with Andover and Cirencester, there was no benefit to split nitrogen compared to single doses.

Overall there was a yield decrease associated with reducing the number of passes through the crop. Over the 3 years, the advantage in favour of the highest compared to the lowest number of passes averaged 0.53 t/ha (0.65 t/ha at Biggleswade, 0.69 t/ha at Cirencester and 0.25 t/ha at Andover). The smallest yield penalties from the minimum pass systems were at Andover, where grass weeds were absent, and in the 2001 season.

3.1.4 Yield Interaction between Establishment Method and Seed Treatment

Sections 3.1.1-3.1.3 highlighted the results of the single trial variables. In the next two sections, results are presented which illustrate the interaction between the different variables.

Table 3.1.10 Yield interaction between establishment and seed treatment 1999-2002 Andover

		Cropping year / rotation position			
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean**
Direct sowing			Yield (t/ha)		
Sibutol	8.87	7.11	3.55	8.67	**7.05**
Sibutol + Latitude	9.71	7.64	3.06	8.76	**7.29**
% increase with Latitude	**+9.5**	**+7.5**	**-13.8**	**+1.0**	**+3.4**
Minimal tillage			Yield (t/ha)		
Sibutol	9.38	8.37	4.28	9.12	**7.79**
Sibutol + Latitude	10.14	8.38	4.53	9.28	**8.08**
% increase with Latitude	**+8.1**	**+0.1**	**+5.8**	**+1.8**	**+3.7**
Plough and press			Yield (t/ha)		
Sibutol	7.54	7.32	4.02	7.87	**6.69**
Sibutol + Latitude	8.54	7.75	4.05	8.10	**7.11**
% increase with Latitude	**+13.3**	**+5.9**	**+0.7**	**+2.9**	**+6.3**
LSD ($p = 0.05$)	0.55	0.66	0.59	0.27	

Mean of three management systems with different number of passes (1999-2001)

There was a trend on this light land site for plough established crops to give greater yield responses to Latitude seed treatment than crops established with minimal tillage and those sown direct. The difference between plough and minimal tillage was most apparent in the second and third wheat. All establishment methods gave their greatest yield response to Latitude seed treatment in the second wheat. In the third wheat the response to Latitude was only significant with the plough and direct sown crops. Since the low yielding year of 2001 was subject to poor establishment conditions and plot damage, it is difficult to draw firm conclusions from this season. However the fifth wheat showed only very small benefits from the take-all seed treatment, irrespective of establishment method, with none of the differences being significant.

Table 3.1.11 Yield interaction between establishment and seed treatment 1999-2002 Cirencester

		Cropping year / rotation position			
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean**
Direct sowing			Yield (t/ha)		
Sibutol	8.81	7.29	5.41	6.93	**7.11**
Sibutol + Latitude	8.80	7.19	5.43	7.16	**7.15**
% increase with Latitude	**-0.1**	**-1.4**	**+0.4**	**+3.3**	**+0.6**
Minimal tillage			Yield (t/ha)		
Sibutol	8.32	6.40	5.87	7.10	**6.92**
Sibutol + Latitude	8.98	6.95	6.14	7.25	**7.33**
% increase with Latitude	**+7.9**	**+8.6**	**+4.6**	**+2.1**	**+5.9**
Plough and press			Yield (t/ha)		
Sibutol	8.21	6.87	6.46	7.08	**7.16**
Sibutol + Latitude	8.66	6.74	6.29	7.21	**7.23**
% increase with Latitude	**+5.5**	**-1.9**	**-2.6**	**+1.8**	**+1.0**
LSD ($p = 0.05$)	0.63	0.78	0.79	0.35	

Mean of three management systems with different number of passes (1999-2001)

There was no advantage to minimal tillage at this site as there was at Andover, and in addition there was no indication that the response to the take-all seed treatment was greater where crops were established with the plough. Indeed it was minimal tillage that tended to produce the greater responses to Latitude, although the only significant yield increase was observed in the second wheat situation. Interestingly there was similarity with Andover in that wheat established direct gave the lowest response to seed treatment over the 4 years of the project, giving no significant benefits in any of the years.

Table 3.1.12 Yield interaction between establishment and seed treatment 1999-2001 Biggleswade

		Cropping year / rotation position		
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat (spring-sown)**	**Mean**
Direct sowing			Yield (t/ha)	
Sibutol	8.65	5.11	2.29	5.35
Sibutol + Latitude	9.39	5.61	2.20	5.73
% increase with Latitude	**+8.6**	**+9.8**	**-3.9**	**+7.1**
Minimal tillage			Yield (t/ha)	
Sibutol	8.32	7.48	3.51	6.44
Sibutol + Latitude	9.42	7.52	3.58	6.84
% increase with Latitude	**+13.2**	**+0.5**	**+1.9**	**+6.2**
Plough and press			Yield (t/ha)	
Sibutol	8.63	6.61	4.40	6.55
Sibutol + Latitude	9.74	6.86	4.45	7.02
% increase with Latitude	**+12.9**	**+3.8**	**+1.1**	**+7.2**
LSD ($p = 0.05$)	0.81	1.23	1.00	

Mean of three management systems with different number of passes

With the exception of the direct-sown blocks the greatest advantage to Latitude was recorded in the second wheat. In that year, the response was only significant in the plough and min till blocks, again highlighting the lack of response in direct-sown crops that was apparent at the Andover and Cirencester sites.

3.1.5 Yield Interaction between Establishment Method, Seed Treatment and Number of Passes

The interaction between all three variables *i.e.* establishment method, seed treatment and number of input passes was examined in 1999, 2000 and 2001. Therefore these yield results indicate whether by adopting reduced establishment techniques growers are more likely to need a higher number of input passes, or whether cost savings could be enhanced by carrying out less passes as well as reduced cultivations.

Table 3.1.13 Interaction between establishment, seed treatment and pass number 1999-2001, Andover

	Establishment method / seed treatment						
Pass	**Direct**		**Min Till**		**Plough**		**Mean Yield**
System	**Sib + Lat.**	**Sibutol**	**Sib + Lat.**	**Sibutol**	**Sib. + Lat.**	**Sibutol**	**(t/ha)**
3 (min pass)	6.78	6.50	7.65	7.31	6.63	6.11	**6.83**
4 (min pass)	6.57	6.24	7.45	7.28	6.82	6.43	**6.80**
7 (control)	7.06	6.79	7.95	7.45	6.89	6.35	**7.08**
Mean	**6.80**	**6.51**	**7.68**	**7.34**	**6.78**	**6.29**	

As a mean over three years reducing the number of core input passes from 7 to 3 reduced yield by 0.25t/ha with little or no evidence that this difference was affected by establishment method or seed treatment. With no grass weeds to compound lower plant populations obtained with reduced cultivation, it is clear that this was the most successful of the three sites for minimum pass husbandry.

Table 3.1.14 Interaction between establishment, seed treatment and pass number 1999-2001, Cirencester

	Establishment method / seed treatment						
Pass	**Direct**		**Min Till**		**Plough**		**Mean Yield**
System	**Sib + Lat.**	**Sibutol**	**Sib + Lat.**	**Sibutol**	**Sib + Lat.**	**Sibutol**	**(t/ha)**
3 (min pass)	6.66	6.95	7.22	6.90	6.95	7.03	**6.95**
4 (min pass)	7.01	6.86	7.12	6.50	6.93	6.86	**6.89**
7 (control))	7.48	7.69	7.74	7.18	7.81	7.65	**7.59**
Mean	**7.05**	**7.17**	**7.36**	**6.86**	**7.23**	**7.18**	

At this site there was evidence that the use of Latitude seed treatment created a greater difference between the lowest and highest pass numbers. Overall the difference in output between the 3-pass and 7-pass control was 0.64 t/ha, with little indication that splitting nitrogen (*i.e.* 4-pass) held any advantage over the single nitrogen dose approach (*i.e.* 3-pass). In all three years there was a significant yield advantage to the 7-pass control.

Table 3.1.15 Interaction between establishment, seed treatment and pass number 1999-2001, Biggleswade

	Establishment method / seed treatment						
Pass	**Direct**		**Min Till**		**Plough**		**Mean Yield**
System	**Sib + Lat.**	**Sibutol**	**Sib + Lat.**	**Sibutol**	**Sib + Lat.**	**Sibutol**	**(t/ha)**
3 (min pass)	5.49	5.08	6.61	6.48	6.67	6.42	**6.13**
4 (min pass)	5.03	4.90	6.61	6.04	7.19	6.54	**6.05**
7 (control)	6.68	6.08	7.30	6.79	7.19	6.68	**6.79**
Mean	**5.74**	**5.35**	**6.84**	**6.44**	**7.02**	**6.55**	

Taking all methods of establishment into consideration the minimum pass systems reduced yield in comparison to the 7-pass control treatment by 0.66 t/ha. On this heavy land site direct-sown wheat established poorly and was unable to compete effectively with the high brome population. In these circumstances there was evidence that fewer passes were less successful with direct sowing than with minimal tillage or ploughing. In addition, as at the Cirencester site, it was clear that the use of Latitude seed treatment created a greater response to more passes through the crop than Sibutol alone.

3.2 Economic analysis

3.2.1 Effect of Establishment Method on Winter Wheat Margins

The following economic analysis of the yield results uses average input and establishment costs for the duration of the project, and a feed wheat grain price of £60/t. Input costs include glyphosate or other herbicide applications made during the inter-crop period, which differed between sites and seasons (see appendix A).

Costs applied:

Direct sowing / roll - £25/ha + £10/ha = **£35/ha**

Disc and press once / drill / roll - £22/ha + £22/ha + £10/ha = **£54/ha**

Plough and press / drill / roll - £38/ha + £22/ha + £10/ha = **£70/ha**

Table 3.2.1 Effect of establishment method on winter wheat margins (£/ha), after deduction of establishment and variable costs 1999-2002 Andover, chalkland soil

	Cropping year / rotation position				
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean Margin (£/ha)**
Direct sowing	301	187	-57	267	**175**
Minimal tillage	311	228	-10	277	**201**
Plough and press	199	169	-41	196	**131**

The most cost-effective establishment method over all four years of the project was minimal tillage (disced and pressed once). Averaged over the four years, this was £26/ha more profitable than direct sowing, and £70/ha more profitable than ploughing. The difference in profitability between establishment methods was reasonably consistent between seasons, a factor far less evident at other sites.

Table 3.2.2 Effect of establishment method on winter wheat margins (£/ha) after deduction of establishment and variable costs 1999-2002 Cirencester, medium loam

	Cropping year / rotation position				
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean Margin (£/ha)**
Direct sowing	235	140	31	129	**134**
Minimal tillage	206	88	48	118	**115**
Plough and press	180	83	57	102	**106**

At this site, despite the presence of chopped straw and resistant blackgrass, direct sowing using the Vaderstad Rapid cultivation drill was the most cost effective establishment method in three years out of four. Ploughing was more cost effective in the very wet autumn of 2000. There was little overall yield difference between establishment methods at this site, so non-inversion techniques were more profitable by virtue of lower costs.

Table 3.2.3 Effect of establishment method on winter wheat margins (£/ha) after deduction of establishment and variable costs 1999-2001 Biggleswade, chalky clay loam

		Cropping year / rotation position		
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat (Spring wheat)**	**Mean Margin (£/ha)**
Direct sowing	276	57	-130	**68**
Minimal tillage	258	176	-61	**124**
Plough and press	261	114	-24	**117**

With no yield penalty in the first season, direct sowing was the most cost-effective method due to its lower cost. In 2000, minimal tillage resulted in the highest yield, with the penalty from direct sowing exceeding the small saving in establishment costs. As with all sites the extremely wet autumn of 2000 severely influenced the profitability of all methods, but especially the non-inversion techniques, so ploughing was the most cost-effective. More importantly, the ploughed blocks were the only ones that could have been sown in the autumn (it was the wetness of the non-inversion blocks that forced drilling to be delayed until the spring).

3.2.2 Effect of Latitude Seed Treatment and Establishment Method on Winter Wheat Margin

The following section examines the cost effectiveness of the take-all seed treatment at the different trial sites and in the different rotation positions *i.e.* second to fifth wheats. Latitude was costed at £27/ha, based on a seed rate of 350 seeds/m^2. Margins in 1999-2001 are the mean of all three of the husbandry systems.

Table 3.2.4 Effect of Latitude seed treatment and establishment method on winter wheat margins (£/ha) after deduction of establishment and variable costs 1999-2002 Andover, chalkland soil

		Cropping year / rotation position			
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean**
Direct sowing			Margin (£/ha)		
Sibutol	290	184	-29	278	**181**
Sibutol + Latitude	314	189	-85	256	**169**
Benefit from Latitude	+**24**	**+5**	**-56**	**-22**	**-12**
Minimal tillage			Margin (£/ha)		
Sibutol	302	241	-4	286	**206**
Sibutol + Latitude	321	215	-16	269	**197**
Benefit from Latitude	+**19**	**-26**	**-12**	**-17**	**-9**
Plough and press			Margin (£/ha)		
Sibutol	183	170	-28	203	**132**
Sibutol + Latitude	216	169	-53	190	**130**
Benefit from Latitude	+**33**	**-1**	**-25**	**-13**	**-2**

Averaged over the four years of the project Latitude seed treatment was not cost effective, however there were differences between seasons (or rotational positions). In the second wheat position (1999) Latitude gave margin increases of between £18-33/ha, however in the third, fourth and fifth wheats Latitude reduced profitability with almost every establishment method. There was an indication that Latitude was slightly more beneficial in plough established crops compared to those established after minimal tillage, and this difference was most apparent in 2000 in the third wheat.

Table 3.2.5 Effect of Latitude seed treatment and establishment method on winter wheat margins (£/ha) after deduction of establishment and variable costs 1999-2002 Cirencester, medium loam

	Cropping year / rotation position				
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat**	**2002 5th Wheat**	**Mean**
Direct sowing			Margin (£/ha)		
Sibutol	248	156	44	135	**146**
Sibutol + Latitude	220	123	18	122	**121**
Benefit from Latitude	**-28**	**-33**	**-26**	**-13**	**-25**
Minimal tillage			Margin (£/ha)		
Sibutol	199	84	52	126	**115**
Sibutol + Latitude	212	90	41	108	**113**
Benefit from Latitude	**+13**	**+6**	**-11**	**-18**	**-2**
Plough and press			Margin (£/ha)		
Sibutol	180	99	74	112	**116**
Sibutol + Latitude	180	64	37	93	**93**
Benefit from Latitude	**0**	**-35**	**-37**	**-19**	**-23**

Again averaged over the four years of the project Latitude was not cost-effective, and there was evidence that the most responsive year was 1999 in the second wheat position. On this medium soil, increases in margin due to Latitude in the second season were restricted to the minimal tillage blocks. With direct sowing there was no benefit from using Latitude in any of the four years.

Table 3.2.6 Effect of Latitude seed treatment and establishment method on winter wheat margins (£/ha) after deduction of establishment and variable costs 1999-2002 Biggleswade, chalky clay loam

	Cropping year / rotation position			
Establishment method	**1999 2nd Wheat**	**2000 3rd Wheat**	**2001 4th Wheat (spring-sown)**	**Mean**
Direct sowing		Margin (£/ha)		
Sibutol	267	55	-114	**69**
Sibutol + Latitude	284	58	-147	**65**
Benefit from Latitude	+**17**	**+3**	**-33**	**-4**
Minimal tillage		Margin (£/ha)		
Sibutol	238	188	-50	**125**
Sibutol + Latitude	277	163	-73	**122**
Benefit from Latitude	+**39**	**-25**	**-23**	**-3**
Plough and press		Margin (£/ha)		
Sibutol	241	120	-13	**116**
Sibutol + Latitude	280	108	-37	**117**
Benefit from Latitude	+**39**	**-12**	**-24**	**+1**

Again there was evidence that Latitude gave profitable returns in the second wheat position but subsequent to that *i.e.* third and fourth wheats its use was not cost-effective. Averaged over all three years it was only after ploughing that treatment was cost-effective, mainly due to the large response in the second wheat.

3.2.3 Effect of pass number, seed treatment and establishment method on winter wheat gross margin (£/ha), and margin after establishment and application cost (£/ha)

The final margin tables below examine the interactions between all three variables in the experiment over the three years. These represent the overall picture as to whether reduced cost establishment techniques combined with minimum pass input husbandry represents a more profitable way forward. For each yield, two margin figures are presented. These are gross margins (value of output – input cost), and overall margin (value of output – input cost, application cost and establishment cost). Wheat has been valued at £60/t. For application costs each pass through the crop has been charged at £7/ha. Where there were differences between seasons, costings have been based on 4,5 and 8 passes. Establishment costs were shown in section 3.2.1.

Table 3.2.7 Effect of pass number, seed treatment and establishment method on gross margin (£/ha) and margin after establishment and application cost (£/ha) 1999 – 2001 Andover, chalkland soil

Husbandry Pass System	**Direct Sib + Lat.**	**Direct Sibutol**	**Min Till Sib + Lat.**	**Min Till Sibutol**	**Plough Sib + Lat.**	**Plough Sibutol**	**Mean**
3 (min pass)							
Gross margin	184	194	236	242	183	179	**203**
Margin (£/ha)	121	131	154	**160**	85	81	**122**
4 (min pass)							
Gross margin	171	178	224	241	194	198	**201**
Margin (£/ha)	101	108	135	152	89	93	**113**
7 (control)							
Gross margin	167	179	221	218	165	160	**185**
Margin (£/ha)	76	88	111	108	39	34	**76**
Mean							
Gross margin	**174**	**184**	**227**	**234**	**181**	**179**	196
Margin (£/ha)	**99**	**109**	**133**	**140**	**71**	**69**	104

The 3-pass system following minimal tillage generated the highest margin after establishment and application costs. There was no indication that lower cost establishment methods reduced the success of minimum pass husbandry. The least cost-effective production technique was plough establishment followed by the 7-pass system, in effect the control treatment. Over the 3 years, Latitude was cost effective only after ploughing, and with the 4-pass and 7-pass systems.

Table 3.2.8 Effect of pass number, seed treatment and establishment method on gross margin (£/ha) and margin after establishment and application cost (£/ha) 1999 – 2001 Cirencester, medium loam

Husbandry	**Direct**		**Min Till**		**Plough**		**Mean**
Pass System	**Sib + Lat.**	**Sibutol**	**Sib + Lat.**	**Sibutol**	**Sib + Lat.**	**Sibutol**	
3 (min pass)							
Gross margin	137	182	171	179	157	190	169
Margin (£/ha)	74	**119**	89	97	59	92	88
4 (min pass)							
Gross margin	159	177	165	155	157	180	166
Margin (£/ha)	89	107	76	66	52	75	78
7 (control)							
Gross margin	155	194	171	164	178	195	176
Margin (£/ha)	64	103	61	54	52	69	67
Mean							
Gross margin	**150**	**184**	**169**	**166**	**164**	**188**	**170**
Margin (£/ha)	**76**	**110**	**75**	**72**	**54**	**79**	**78**

The 3-pass system following direct sowing generated the optimum margin after establishment and application cost. Although this combination was the most profitable, there was less advantage to reducing the number of passes with this method of establishment, than was the case with minimal tillage or ploughing. Latitude was not cost-effective with the direct or plough established crops, but there was small benefit (averaging £3/ha) after minimal tillage in the 4-pass and 7-pass systems.

Table 3.2.9 Effect of pass number, seed treatment and establishment method on gross margin (£/ha) and margin after establishment and application cost (£/ha) 1999 – 2001 Biggleswade, chalky clay loam

Husbandry Pass System	**Direct Sib + Lat.**	**Sibutol**	**Min Till Sib + Lat.**	**Sibutol**	**Plough Sib + Lat.**	**Sibutol**	**Mean**
3 (min pass)							
Gross margin	96	100	173	193	176	190	155
Margin (£/ha)	33	37	91	**111**	78	92	74
4 (min pass)							
Gross margin	69	89	172	167	207	197	150
Margin (£/ha)	-1	19	83	78	102	92	62
7 (control)							
Gross margin	134	129	184	181	177	174	163
Margin (£/ha)	43	38	74	71	51	48	54
Mean							
Gross margin	**100**	**106**	**176**	**180**	**187**	**187**	**156**
Margin (£/ha)	**25**	**31**	**83**	**87**	**77**	**77**	**63**

The 3-pass system following minimal tillage generated the optimum margin after establishment and application cost. With direct sowing there was no advantage to minimum pass husbandry, whereas with minimal tillage and ploughing fewer passes produced the best margins. Thus where establishment is severely compromised and grass weed competition is strong, minimum pass husbandry is less likely to improve profitability.

3.3 Energy Analysis (conducted and reported by IACR Long Ashton Research Station)

3.3.1 Energy Analysis of the Establishment Techniques

This analysis considers only the direct and indirect energy costs of operations to cultivate the ground and drill the wheat. Other energy costs associated with the establishment methods such as herbicides are considered in the input analysis.

Table 3.3.1 shows that on all three sites the plough-based method used the most direct and indirect energy, whilst direct sowing used the least energy. This is explained by the direct-sown method consisting of a single pass by a tractor and cultivating drill compared to the minimal tillage (disc-based) system and plough based methods, which required an additional pass prior to drilling to create a seed bed.

The differences between the sites can be explained by the different soil types, which affected both the size of tractor and the torque required to pull the implement as well as the speed of cultivation. This affected both the direct (diesel and oil use) and indirect (energy embodied in machines and implements) energy costs. The soil at the Andover site allowed faster forward speeds than the Cirencester and Biggleswade sites (see appendix B).

The much higher energy costs at the Biggleswade site for the plough-based method were attributed to the pressing of the soil after ploughing as a separate operation.

Table 3.3.1 Direct and indirect energy costs (MJ/ha) of cultivations and drilling per year under the three establishment methods

Site	Direct	Min till	Plough
	Direct costs (MJ/ha)		
Andover	602	835	1256
Biggleswade	682	1039	2386
Cirencester	642	1118	1465
	Indirect costs (MJ/ha)		
Andover	88	126	203
Biggleswade	88	152	440
Cirencester	88	162	244
	Total costs (MJ/ha)		
Andover	690	961	1459
Biggleswade	770	1191	2826
Cirencester	730	1280	1709

3.3.2 Energy Analysis of Inputs

Table 3.3.2. Energy costs (MJ/ha) of inputs (including the cost of application) under each establishment method x crop husbandry system at each site in 1999-2000

Site	Crop husbandry system 3-pass	4-pass	7-pass
		MJ/ha	
Andover			
Direct	10561	10596	11162
Min till	10561	10596	11162
Plough	10462	10496	11062
Biggleswade			
Direct	11546	11580	12098
Min till	11546	11580	12098
Plough	11546	11580	12098
Cirencester			
Direct	11355	11389	11782
Min till	11355	11389	11782
Plough	11355	11389	11782
Average			
Direct Drill	11154	11187	11675
Min-Till	11154	11187	11675
Plough based	11121	11153	11641

In 1999-2000 comparing sites it was apparent that the Biggleswade site had the highest input energy costs and Andover the lowest (Table 3.3.2). In 2000-2001 Cirencester overall had higher input energy costs and Biggleswade sown with spring wheat had the lowest (Table 3.3.3).

Table 3.3.3 Energy costs (MJ/ha) of inputs (including the cost of application) under each establishment method x crop husbandry system at each site in 2000-2001

Site	Crop husbandry system 3-pass	4-pass	7-pass
		MJ/ha	
Andover			
Direct	10633	10668	10964
Min till	10633	10668	10964
Plough	10473	10506	10805
Biggleswade			
Direct	8207	8241	8332
Min till	8207	8241	8332
Plough	8207	8241	8332
Cirencester			
Direct	10985	11020	11376
Min till	10985	11020	11376
Plough	10985	11020	11376
Average			
Direct	9942	9976	10224
Min till	9942	9976	10224
Plough	9888	9922	10171

3.3.3 Total Energy Cost per Hectare and per Tonne of Wheat

The total energy used per hectare (excluding combining and drying energy costs) is shown in Tables 3.3.4 and 3.3.5. The data shows that at all sites the establishment method had only a slight effect on the amount of energy used per hectare under the different crop husbandry systems.

The energy used to produce a tonne of wheat under the nine different combinations varied between sites. The combination that produced a tonne of wheat for the lowest energy cost in 2000 (Table 3.3.4) was minimal tillage based establishment with the 7-pass husbandry system at Andover. The highest energy cost per tonne of production occurred under direct sowing with the 4-pass husbandry system, at Biggleswade (these plots also had the lowest mean yield).

In 2001 (Table 3.3.5) the combination that produced a tonne of wheat for the lowest energy cost was plough based establishment with the 4-pass husbandry system at Cirencester (these plots had the highest mean yield). The highest energy cost per tonne of production was the direct-sown spring wheat with the 4-pass husbandry system at Biggleswade (lowest mean yield).

Table 3.3.4. Total energy costs per hectare (MJ/ha), yields and MJ per tonne at the three sites under the different establishment methods and crop husbandry systems in 1999-2000

	MJ per Hectare			Yields (t) per Hectare			MJ/t		
Andover	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass
Direct	11252	11286	11852	7.28	7.26	7.60	1546	1555	1559
Min till	11522	11557	12123	8.23	7.92	8.98	1400	1459	1350
Plough	11921	11955	12521	7.51	7.33	7.77	1587	1631	1611
Biggleswade									
Direct	12316	12350	12868	5.15	4.83	6.10	2391	2557	2110
Min till	12737	12771	13289	6.73	7.04	8.73	1893	1814	1522
Plough	14371	14406	14924	6.18	6.25	7.79	2325	2305	1916
Cirencester									
Direct	12086	12119	12512	6.82	6.83	8.07	1772	1774	1550
Min till	12636	12669	13062	6.76	6.22	7.05	1869	2037	1853
Plough	13064	13098	13491	6.43	6.37	7.64	2032	2056	1766
Average									
Direct	11252	11286	11852	6.42	6.31	7.26	1903	1962	1739
Min till	11522	11557	12123	7.24	7.06	8.25	1721	1770	1574
Plough	11921	11955	12521	6.71	6.65	7.73	1982	1997	1764

Table 3.3.5. Total energy costs per hectare (MJ/ha), yields and MJ per tonne at the three sites under the different establishment methods and crop husbandry systems in 2000-2001

	MJ per Hectare			Yields (t) per Hectare			MJ/t		
Andover	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass
Direct	11323	11357	11654	3.45	2.98	3.48	3282	3811	3349
Min till	11594	11628	11925	4.78	4.39	4.06	2426	2679	2937
Plough	11932	11965	12264	3.89	4.70	3.51	3067	2546	3494
Biggleswade									
Direct	8977	9011	9101	2.00	1.93	2.82	4488	4669	3227
Min till	9398	9432	9522	3.55	3.41	3.68	2647	2766	2588
Plough	11033	11067	11157	4.58	4.48	4.22	2409	2470	2644
Cirencester									
Direct	11715	11750	12106	4.89	5.49	5.46	2396	2140	2217
Min till	12265	12300	12656	6.49	5.90	5.66	1890	2085	2236
Plough	12694	12729	13085	6.29	6.89	5.99	2034	1847	2185
Average									
Direct	10672	10706	10954	3.49	3.47	3.92	3058	3085	2794
Min till	11086	11120	11368	4.94	4.57	4.47	2244	2433	2543
Plough	11886	11921	12169	4.90	5.36	4.58	2426	2224	2657

Table 3.3.6. Three-year mean total energy costs per hectare (MJ/ha), yields and MJ per tonne at the three sites under the different establishment methods and crop husbandry systems in 1998-2001

	MJ per Hectare			Yields (t) per Hectare			MJ/t		
Andover	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass
Direct	11262	11295	11768	6.64	6.40	6.93	2015	2206	2042
Min till	11532	11567	12039	7.48	7.36	7.70	1681	1762	1829
Plough	11901	11934	12408	6.37	6.62	6.62	2063	1898	2185
Biggleswade									
Direct	10661	10695	11083	5.29	4.97	6.38	2702	2848	2147
Min till	11023	11057	11445	6.59	6.28	7.05	1897	1962	1809
Plough	12658	12692	13080	6.55	6.87	6.94	2049	2017	2018
Cirencester									
Direct	11668	11701	12140	6.76	6.98	7.58	1825	1739	1683
Min till	12218	12251	12690	7.06	6.82	7.46	1747	1844	1789
Plough	12603	12636	13076	6.90	7.01	7.73	1854	1820	1757
Average									
Direct	10986	11020	11478	6.25	6.12	6.96	2020	2055	1875
Min till	11332	11366	11824	7.04	6.82	7.40	1703	1787	1758
Plough	11988	12022	12480	6.60	6.83	7.10	1896	1819	1899

Lowest energy cost per tonne (MJ/t) in all the husbandry systems was at Andover and Biggleswade in the minimal tillage blocks. At Cirencester in the 3-pass system, minimal tillage blocks had the lowest MJ/t, in the 4-pass and 7-pass systems direct-sown blocks had the lowest MJ/t. The overall average shows that direct-sown blocks used the lowest energy per hectare (MJ/ha), but that the minimal tillage blocks had the highest yields and lowest energy cost per tonne (MJ/t).

Table 3.3.7. Potential savings in energy costs per hectare (MJ/ha) and MJ per tonne at Andover and Cirencester 2001

	MJ per Hectare			Yields (t) per Hectare			MJ/t		
Andover	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass	3-pass	4-pass	7-pass
Direct	9715	9749	10046	3.45	2.98	3.48	2816	3271	2887
Min till	10603	10637	10934	4.78	4.39	4.06	2218	2423	2693
Plough	10941	10357	10656	3.89	4.70	3.51	2813	2204	3036
Cirencester									
Direct	10615	10650	11006	4.89	5.49	5.46	2171	1940	2016
Min till	10996	11031	11387	6.49	5.90	5.66	1694	1870	2012
Plough	11594	11629	11985	6.29	6.89	5.99	1843	1688	2001

Nitrogen sampling post harvest at Andover and Cirencester showed that savings could retrospectively have been made in applied nitrogen fertiliser, of between 19 kg/ha (Andover minimal tillage blocks) and 32 kg/ha (Andover ploughed blocks). If these amounts of nitrogen had not been applied in spring 2001, savings in energy for MJ per tonne (Table 3.3.7) could have been in the range of 6% (Cirencester direct sowing with the 7-pass system) and 14% (Andover direct sowing with the 4-pass and 7-pass systems). Residual nitrogen levels at Biggleswade were very low, therefore savings could not have been made in applied nitrogen in 2001.

Table 3.3.8. Average Time (min/ha), Cost (£/ha), Diesel (l/ha) and Total C emission (Kg C/ha (direct and indirect energy)) for crop establishment 1998-2000

	Minutes/ha	Contractor * £/ha	Farmer * £/ha	Diesel l/ha	Co_2 release (Carbon Kg/ha)
Andover					
Direct sowing	33	22	15	15.6	17.2
Minimal tillage	46	50	31	21.7	24.0
Plough and press	80	69	56	32.5	36.8
Biggleswade					
Direct sowing	33	22	15	17.7	18.9
Minimal tillage	59	50	31	27.0	29.6
Plough and press	133	77	61	61.9	68.4
Cirencester					
Direct sowing	33	22	15	16.7	18.0
Minimal tillage	62	50	31	29.0	31.8
Plough and press	95	69	56	38.0	43.2

* Based on Nix prices 2000

The ploughed blocks at Biggleswade took the longest time to establish (min/ha) due to the heavier soil at this site and pressing of the soil after ploughing as a separate operation, this extra pass at Biggleswade also increased the establishment cost (£/ha). Least diesel used and lower carbon emissions were in the direct-sown blocks at all sites. Of the minimal tillage, disc-based blocks, Andover used the least diesel and released less CO_2 due to the use of a higher horsepower tractor, travelling faster with a greater implement width than at Biggleswade and Cirencester (appendix B). Most diesel and highest CO_2 emissions were with the plough-based establishment method at Biggleswade.

3.4 Grain Quality

3.4.1 Effects of Establishment Method, Seed Treatment and Number of Passes on Specific Weight

Establishment technique, seed treatment and number of input passes were all observed to have a significant effect on specific weight over the course of the four years. However, not all trials showed the same differences, and in some cases there were interactions between factors. Tables 3.4.1-3.4.4 highlight some of these effects. Note that the specific weights shown are as recorded off combine without further cleaning of the grain sample.

At Cirencester in 1999, direct sowing produced grain with a higher specific weight than after ploughing. The highest specific weight also resulted from the greatest number of passes. The use of Latitude seed treatment increased specific weight slightly.

Table 3.4.1 The effect of establishment method, seed treatment and number of input passes on specific weight at Cirencester in 1999

Establishment method	Specific weight (kg/hl)	Seed treatment	Specific weight (kg/hl)	Husbandry Pass System	Specific weight (kg/hl)
Direct sowing	71.1	Sibutol	69.6	3-pass	69.5
Minimal tillage	70.1	Sibutol + Latitude	70.5	4-pass	69.2
Plough / press	69.1			7-pass	71.5
LSD (P = 0.05)	1.2	LSD (P = 0.05)	0.9	LSD (P = 0.05)	0.8

The greatest number of passes again produced grain with the highest specific weight at both Andover and Cirencester in 2000. At Biggleswade, minimal tillage resulted in a higher specific weight than, which in turn was higher than direct sowing.

Table 3.4.2 The effect of establishment method (at Biggleswade) and number of input passes (at Andover and Cirencester) on specific weight in 2000

Biggleswade		Andover		Cirencester	
Establishment method	**Specific weight (kg/hl)**	**Husbandry Pass System**	**Specific weight (kg/hl)**	**Husbandry Pass System**	**Specific weight (kg/hl)**
Direct sowing	71.6	3-pass	68.4	3-pass	68.6
Minimal tillage	74.3	4-pass	67.5	4-pass	68.1
Plough / press	72.9	7-pass	68.8	7-pass	70.5
LSD (P = 0.05)	0.8	LSD (P = 0.05)	0.8	LSD (P = 0.05)	0.4

In both 2001 and 2002, direct sowing again produced some of the lowest specific weights. However, in contrast to the previous year, ploughing resulted in the highest specific weights in 2001.

Table 3.4.3 The effect of establishment method on specific weight in 2001

Establishment method	Andover	Biggleswade
	Specific weight (kg/hl)	
Direct sowing	64.6	66.7
Minimal tillage	68.2	69.1
Plough / press	69.8	71.1
LSD (P = 0.05)	-	1.2

Table 3.4.4 The effect of establishment method on specific weight at Andover and Cirencester in 2002

Establishment method	Specific Weight (kg/hl)	
	Andover	Cirencester
Direct sowing	69.9	72.2
Minimal tillage	70.6	73.1
Plough / press	70.6	73.5
LSD (p = 0.05)	0.5	0.6

3.4.2 Effect of Establishment, Seed Treatment and Number of Passes on Thousand Grain Weight

Number of input passes had the most consistent influence on thousand grain weight, but seed treatment and establishment method had a significant effect in some of the trials (Tables 3.4.5-3.4.8). In 1999 and 2000, the 7 pass systems produced the highest TGW, and the 4 pass systems often produced the lowest. Latitude seed treatment increased TGW at Andover and Cirencester in 1999.

Table 3.4.5 The effect of seed treatment and number of input passes on TGW at Andover in 1999

Seed Treatment	Thousand Grain Weight (g)			LSD (p = 0.05)
	3-pass	4-pass	7-pass	
Sibutol	49.8	51.3	52.0	2.1
Sibutol + Latitude	52.9	50.3	53.6	2.1
LSD (p = 0.05)	2.5	n.s.	2.5	

Table 3.4.6 The effect of seed treatment and number of input passes on TGW at Cirencester in 1999

Seed Treatment	Thousand Grain Weight (g)	Husbandry Pass System	Thousand Grain Weight (g)
Sibutol	39.8	3-pass	41.3
Sibutol + Latitude	41.8	4-pass	39.1
		7-pass	41.9
LSD (p = 0.05)	1.4	LSD (p = 0.05)	1.2

Table 3.4.7 The effect of number of input passes on TGW at Biggleswade and Cirencester in 2000

Husbandry Pass System	Thousand Grain Weight (g)	
	Biggleswade	Cirencester
3-pass	39.1	40.1
4-pass	39.2	39.5
7-pass	41.6	43.2
LSD (p = 0.05)	1.7	1.1

In 2001, there was an interaction between establishment method and number of input passes at Cirencester. The 7-pass system gave the highest TGW after direct sowing, but the lowest TGW after minimal tillage or ploughing.

Table 3.4.8 The effect of establishment method and number of input passes on TGW at Cirencester in 2001

Establishment method	**Thousand Grain Weight (g)**			LSD (p = 0.05)
	3-pass	4-pass	7-pass	
Direct sowing	40.9	42.6	44.6	2.9
Minimal tillage	45.7	42.3	41.8	2.9
Plough / press	44.8	46.5	42.8	2.9
LSD (p = 0.05)	3.4	3.4	n.s.	

3.4.3 Effect of Establishment Method and Number of Input Passes on Grain Protein Content and Hagberg Falling Number

Samples from the Andover site were tested for % grain protein content and Hagberg Falling Number in 1999 and 2000. These were not replicated, but mean values are presented in Tables 3.4.9 and 3.4.10. Both grain proteins and Hagbergs tended to be higher in 2000 than in 1999, but neither establishment method nor number of input passes had any conclusive effects.

Table 3.4.9 The effect of establishment method on grain protein and Hagberg at Andover

Establishment	**Direct sowing**	**Minimal tillage**	**Plough and press**
Year	Grain Protein Content (%)		
1999	10.7	10.5	11.3
2000	11.2	11.8	11.7
Year	Hagberg Falling Number		
1999	227	223	201
2000	322	303	354

Table 3.4.10 The effect of number of input passes on grain protein and Hagberg at Andover

Number of passes	**3-pass**	**4-pass**	**7-pass**
Year	Grain Protein Content (%)		
1999	11.6	10.3	10.7
2000	11.6	11.6	11.5
Year	Hagberg Falling Number		
1999	218	219	214
2000	348	332	299

3.5 Crop Structure

3.5.1 Effect of Establishment Method on Plant and Ear Populations

Establishment technique had a significant effect on plant populations in almost all trials over the four year period, but resulting ear populations were less often influenced (Tables 3.5.1-3.5.3). In most cases, direct sowing produced the lowest plant counts, and ploughing the highest. The greatest differences were at Andover and Biggleswade (spring wheat) in 2001, which followed the very wet autumn of 2000. Minimal tillage gave significantly lower plant populations than ploughing in about half of the trials.

At Andover in particular, direct sowing often produced the highest ear populations, even where it had resulted in the lowest plant populations. However 2001 was an exception, due to the overwhelming differences in plant population. Ploughing gave the highest ear counts at Cirencester in 2002.

Table 3.5.1 The effect of establishment method on plant and ear populations at Andover

Establishment	**Direct sowing**	**Minimal tillage**	**Plough and press**	LSD (p = 0.05)
Year	Number of plants per m2			
1999	199	219	250	27
2000	204	243	268	16
2001	96	192	199	31
2002	225	237	215	n.s.
Mean	181	223	233	
Year	Number of ears per m2			
1999	415	423	360	21
2000	391	389	371	n.s.
2001	145	178	188	23
2002	557	530	451	49
Mean	377	380	343	

Table 3.5.2 The effect of establishment method on plant and ear populations at Cirencester

Establishment	**Direct sowing**	**Minimal tillage**	**Plough and press**	LSD (p = 0.05)
Year	Number of plants per m2			
1999	184	232	280	16
2000	195	193	191	n.s.
2001	174	222	222	28
2002	216	248	282	26
Mean	192	224	244	
Year	Number of ears per m2			
1999	300	295	300	n.s.
2000	372	349	364	n.s.
2001	276	274	291	n.s.
2002	280	313	350	35
Mean	307	308	326	

Table 3.5.3 The effect of establishment method on plant and ear populations at Biggleswade

Establishment	**Direct sowing**	**Minimal tillage**	**Plough and press**	LSD (p = 0.05)
Year	Number of plants per m2			
1999	104	126	124	5
2000	220	263	260	25
2001	152	215	280	50
Mean	159	201	221	
Year	Number of ears per m2			
1999	413	387	386	n.s.
2000	344	410	418	62
2001	201	234	234	n.s.
Mean	319	344	346	

Whilst there were no significant differences in ear population between establishment methods at Biggleswade in 1999, there was an interaction between establishment and number of input passes. There were significantly more ears per m2 in the 7-pass direct-sown than in the 3-pass or 4-pass. In contrast, there were significantly less ears per m2 in the 7-pass ploughed blocks than in the 4-pass (Table 3.5.4).

Table 3.5.4 The combined effect of establishment and pass number on ear populations at Biggleswade in 1999

Establishment	**Direct sowing**	**Minimal tillage**	**Plough and press**	LSD (p = 0.05)
Pass System	Number of ears per m2			
3-pass	404	411	379	n.s.
4-pass	356	378	423	67
7-pass	480	371	356	67
LSD (p = 0.05)	51	n.s.	51	

3.6 Disease Levels

The incidences of root take-all, stem-base eyespot or Fusarium, and whiteheads, were assessed at intervals from the autumn through to the summer at all sites over the four years. In addition, levels of foliar disease were assessed during the spring and summer of 1999, 2000 and 2001

3.6.1 Effect of Establishment Method and Seed Treatment on Take-all

The effects of establishment technique and seed treatment on take-all incidence (1999) or severity (2000-2002) are shown in Tables 3.6.1-3.6.4. At Biggleswade, differences were only apparent in 1999.

Latitude seed treatment had decreased take-all incidence by an average of two-thirds in November 1998, but this decrease was reduced to half by February 1999. Direct sowing resulted in the highest take-all incidence in November, and ploughing the lowest (except at Biggleswade where minimal tillage was lower). By February, differences between establishment systems were small, but direct still tended to be highest.

Table 3.6.1 Effect of establishment method and seed treatment on take-all incidence 1999

Date assessed	**Location**	**Andover**		**Cirencester**		**Biggleswade**	
	Seed	Sibutol	Latitude	Sibutol	Latitude	Sibutol	Latitude
	Establishment	**Take-all Incidence (%)**					
November 1998	Direct sowing	8.9	2.5	13.3	3.9	4.1	1.8
	Minimal tillage	7.3	1.4	5.1	2.9	1.7	0.3
	Plough / press	3.9	0.8	2.2	0.7	2.4	1.4
	Mean	6.7	1.6	6.9	2.5	2.7	1.2
February 1999	Direct sowing	97	47	93	57	97	53
	Minimal tillage	80	40	70	37	97	40
	Plough / press	83	37	97	37	83	50
	Mean	87	41	87	44	92	48

At Andover and Cirencester, Latitude reduced take-all severity in both November and February. In 1999/00, severity was decreased typically by 40%, and by 50-60% in 2000/01. Establishment method had less effect, but at both locations in February 2000 there was more take-all after ploughing than following direct sowing.

Table 3.6.2 Effect of establishment method and seed treatment on take-all severity 2000

Location	Andover		Cirencester	
Date assessed	Nov 1999	Feb 2000	Nov 1999	Feb 2000
Establishment	Take-all Severity (angular transformed means)			
Direct sowing	2.66	3.57	-	3.46
Minimal tillage	2.33	3.83	-	4.04
Plough / press	2.36	4.26	-	4.63
LSD (p = 0.05)	n.s.	n.s.	-	0.67
Seed Treatment	Take-all Severity (angular transformed means)			
Sibutol	3.14	4.99	2.52	5.14
Sib. + Latitude	1.76	2.78	1.60	2.94
LSD (p = 0.05)	0.69	0.50	0.63	0.70

Table 3.6.3 Effect of seed treatment on take-all severity 2001

Location	Seed Treatment	Andover	Cirencester
	Take-all Severity (angular transformed means)		
November 2000	Sibutol	1.90	0.60
	Sib. + Latitude	0.67	0.34
	LSD (p = 0.05)	0.44	0.26
February 2001	Sibutol	4.03	3.44
	Sib. + Latitude	2.12	1.41
	LSD (p = 0.05)	0.84	0.71

In 2002, Latitude was still showing a significant reduction in take-all severity in May, but there was little difference by August. At Andover, severity was highest after ploughing and lowest after direct sowing.

Table 3.6.4 Effect of establishment method and seed treatment on take-all severity 2002

Location	Andover		Cirencester	
Date assessed	May 2002	Aug 2002	May 2002	Aug 2002
Establishment	Take-all Severity Index			
Direct sowing	5.3	18.6	0.88	31.0
Minimal tillage	9.3	24.1	0.16	10.4
Plough / press	14.4	52.1	0.74	23.0
LSD (p = 0.05)	2.8	3.8	n.s.	n.s.
Seed Treatment	Take-all Severity Index			
Sibutol	11.6	33.9	1.06	20.9
Sib. + Latitude	7.7	29.3	0.13	22.1
LSD (p = 0.05)	2.3	3.1	0.79	n.s.

3.6.2 Effect of Establishment Method on Eyespot and Fusarium Incidence

The incidence of eyespot in February was consistently lower after direct sowing than following ploughing in both 1999 (Table 3.6.5) and 2000 (Table 3.6.6). Similarly, eyespot severity in August 2002 was significantly lower in direct-sown blocks (Table 3.6.7). Minimal tillage did not show the same effect. Fusarium incidence varied between establishment methods, but there was a slight indication of higher levels following minimal tillage.

Table 3.6.5 Effect of establishment method on eyespot and Fusarium incidence in February 1999

Location	**Andover**		**Cirencester**		**Biggleswade**	
Establishment	% eyespot	% Fusarium	% eyespot	% Fusarium	% eyespot	% Fusarium
Direct sowing	12	53	15	48	18	47
Minimal tillage	25	58	25	53	30	57
Plough / press	20	53	30	38	22	42

Table 3.6.6 Effect of establishment method on eyespot and Fusarium incidence in February 2000

Location	**Andover**		**Cirencester**	
Establishment	% eyespot	% Fusarium	% eyespot	% Fusarium
Direct sowing	-	36	9	24
Minimal tillage	-	42	18	25
Plough / press	-	34	22	31
LSD (p = 0.05)	-	6.4	8.4	5.8

(Data shown as angular transformations)

Table 3.6.7 Effect of establishment method on eyespot severity in August 2002

Location	**Andover**	**Cirencester**
Establishment	Eyespot severity index	
Direct sowing	26	4.7
Minimal tillage	34	7.7
Plough / press	36	13.0
LSD (p = 0.05)	5.2	4.4

3.6.3 Effect of Establishment Method and Seed Treatment on Whitehead Incidence

Whiteheads were observed in two of the four years, with the highest numbers recorded at Biggleswade in July 1999. In that year, there were substantially less whiteheads where Latitude seed treatment had been used (Table 3.6.8). At Biggleswade and Cirencester, there were more whiteheads after ploughing than after direct sowing, but this was not the case at Andover, especially in 2001 (Table 3.6.9).

Table 3.6.8 Effect of establishment method and seed treatment on whitehead incidence 1999

Location	**Andover**		**Biggleswade**	
Seed	Sibutol	Latitude	Sibutol	Latitude
Establishment	Whiteheads per plot			
Direct sowing	21	6	332	183
Minimal tillage	12	1	429	221
Plough / press	15	6	586	294
Mean	16	4	449	233

Table 3.6.9 Effect of establishment method on whitehead incidence 2001

Location	**Andover**	**Cirencester**	**Biggleswade**
Establishment	Whiteheads per plot (square root transformed means)		
Direct sowing	2.49	0.61	0.40
Minimal tillage	2.56	1.27	0.43
Plough / press	1.33	1.46	1.17
LSD (p = 0.05)	0.60	0.51	0.22

3.6.4 Effect of Establishment Method and Number of Passes on Diseased Leaf Area

Both number of input passes and, less predictably, establishment technique had an influence on foliar disease incidence. The only disease present at meaningful levels in all trials was *Septoria tritici*, and this was assessed at intervals from April through to July. All data shown in the tables is presented as angular transformations.

In almost all cases, incidence of *S. tritici* was significantly lower following direct sowing than after ploughing (Tables 3.6.10-3.6.12). At Cirencester in 1999, and at Biggleswade in 2000, this difference was still apparent in July. Minimal tillage was mostly intermediate, but sometimes also significantly lower than after ploughing.

Table 3.6.10 Effect of establishment method on *Septoria tritici* incidence in 1999

Location	**Andover**	**Cirencester**		**Biggleswade**
Date and leaf assessed	April GS31	April GS31	July GS75 leaf 2	April GS31
Establishment	Diseased leaf area (*Septoria tritici*)			
Direct sowing	16.7	17.7	9.6	12.2
Minimal tillage	22.5	21.3	9.8	15.9
Plough / press	22.5	22.5	14.2	15.1
LSD (p = 0.05)	3.7	2.6	2.9	2.9

Table 3.6.11 Effect of establishment method on *Septoria tritici* incidence in 2000

Location	**Cirencester**		**Biggleswade**
Date and leaf assessed	April GS31 leaf 7	May GS37	July GS77 leaf 3
Establishment	Diseased leaf area (*Septoria tritici*)		
Direct sowing	26.0	8.9	16.8
Minimal tillage	28.0	9.4	21.3
Plough / press	32.6	10.9	25.6
LSD (p = 0.05)	3.3	1.0	4.3

Table 3.6.12 Effect of establishment method on *Septoria tritici* incidence in 2001

Location	**Andover**		**Cirencester**
Date and leaf assessed	June GS39 leaf 5	July GS80 leaves 1-3	June GS39 leaves 1-5
Establishment	Diseased leaf area (*Septoria tritici*)		
Direct sowing	2.3	1.36	3.1
Minimal tillage	2.5	0.42	4.0
Plough / press	4.5	0.96	5.8
LSD (p = 0.05)	0.84	0.37	0.61

There was significantly less *S. tritici* in the 7-pass systems (that received three fungicide sprays) than in the 3 or 4-pass systems (that received only one fungicide spray) at both Andover and Cirencester in 1999 (Table 3.6.13) and 2000 (Table 3.6.14). There were no differences between the 3 and 4-pass systems.

Table 3.6.13 Effect of number of passes on *Septoria tritici* incidence in 1999

Location	**Andover**		**Cirencester**
Date and leaf assessed	May GS45 leaf 3	July GS75 leaf 2	May GS45 leaf 3
Pass System	Diseased leaf area (*Septoria tritici*)		
3 (min pass)	2.5	13.6	2.6
4 (min pass)	2.3	12.9	2.9
7 (control)	0.8	5.0	0.5
LSD (p = 0.05)	1.0	3.1	0.8

Table 3.6.14 Effect of number of passes on *Septoria tritici* incidence in 2000

Location	**Andover**		**Cirencester**
Date and leaf assessed	May GS37	July GS77 leaf 3	July GS77 leaf
Pass System	Diseased leaf area (*Septoria tritici*)		
3 (min pass)	6.2	12.9	27.2
4 (min pass)	5.9	14.0	31.2
7 (control)	3.9	5.6	13.5
LSD (p = 0.05)	0.8	2.6	2.6

3.7 Weed Infestation

Weed populations were recorded in all trials over the course of the project. Broad-leaved weeds were present at all locations, and these were assessed in November prior to their removal by autumn herbicide treatments. Grass weeds were mainly a problem at Biggleswade and Cirencester, and these were assessed both before and after herbicides had been applied. Only the effects of establishment technique were examined.

3.7.1 Effect of Establishment Method on Broad-Leaved Weed Incidence

At Andover and Cirencester, broad-leaved weed populations were significantly higher after ploughing than after direct sowing or minimal tillage (Tables 3.7.1-3.7.3). The dominant species were groundsel at Andover and ivy-leaved speedwell at Cirencester. At Biggleswade, where common speedwell was the main species, populations were also lowest in the direct-sown blocks, but minimal tillage was more similar to ploughing.

Table 3.7.1 The effect of establishment method on broad-leaved weed populations in November 1998

Establishment Method	Number of Broad-Leaved Weeds per m^2		
	Andover	**Cirencester**	**Biggleswade**
Direct sowing	8.0	25.7	5.1
Minimal tillage	12.7	29.7	48.2
Plough / press	106.2	161.9	68.3
LSD (p = 0.05)	37.3	51.1	25.0

Table 3.7.2 The effect of establishment method on broad-leaved weed populations in November 1999

Establishment Method	Number of Broad-Leaved Weeds per m^2 (figures presented as square root transformations)		
	Andover	**Cirencester**	**Biggleswade**
Direct sowing	0.6	3.4	0.6
Minimal tillage	1.6	5.1	1.8
Plough / press	5.0	9.9	2.2
LSD (p = 0.05)	0.9	3.2	n.s.

Table 3.7.3 The effect of establishment method on broad-leaved weed populations in November 2000

Establishment Method	Number of Broad-Leaved Weeds per m^2 (figures presented as square root transformations)		
	Andover	**Cirencester**	**Biggleswade**
Direct sowing	0.1	0.0	0.0
Minimal tillage	0.1	0.1	0.8
Plough / press	2.2	3.5	0.9
LSD (p = 0.05)	1.5	2.1	0.8

3.7.2 Effect of Establishment Method on Grass Weed Incidence

The main grass weed present at Cirencester was blackgrass (confirmed as RRR fop-resistant), which reached problem levels from the second year onwards (Table 3.7.4). Initially there were no significant differences between establishment methods, but subsequently head counts were significantly lower after ploughing than after direct sowing (in 2001) or minimal tillage (in 2002).

Table 3.7.4 The effect of establishment method on blackgrass incidence at Cirencester

Establishment Method	**Number of blackgrass panicles per plot (144m^2)** (figures presented as square root transformations)			**No. of blackgrass heads per m^2**
	July 2000	**November 2000**	**July 2001**	**July 2002**
Direct sowing	46.9	3.6	73.5	85
Minimal tillage	65.3	5.5	52.2	108
Plough / press	55.8	3.5	46.8	77
LSD (p = 0.05)	n.s.	n.s.	26.4	20

At Biggleswade, the main grass weed problem was bromes (mostly great and sterile brome). However, both blackgrass and wild oats were also present (Table 3.7.5). At the end of the first season, the highest blackgrass populations were recorded after ploughing, but by July 2000 it was the direct-sown that had the most, with very little in the minimal tillage or ploughed blocks. Brome populations were relatively low in the first year, with minimal tillage the worst affected. Subsequent to this, levels in the direct-sown blocks increased rapidly, peaking in 2000 (note that the crop was spring-sown in 2001 allowing a non-selective herbicide to be applied pre-drilling). In contrast, brome remained more or less absent after ploughing.

Table 3.7.5 The effect of establishment method on grass weed incidence at Biggleswade

Establishment Method	**Number of grass weed panicles per plot (144m^2)** (figures presented as square root transformations)					
	Blackgrass July 1999	**Brome Nov. 1999**	**Brome Feb. 2000**	**Blackgrass July 2000**	**Brome July 2000**	**Brome July 2001**
Direct sowing	1.3	3.9	5.1	3.5	41.7	27.1
Minimal tillage	2.7	1.8	1.0	0.4	8.8	1.9
Plough / press	19.2	0.1	0.0	0.0	0.1	0.0
LSD (p = 0.05)	10.6	2.6	2.5	1.7	19.4	9.4

3.8 Soil Nitrogen

Levels of soil mineral nitrogen at 0-30cm depth were measured for each location at intervals during the first three years of the project. Only the effects of establishment technique were examined (Table 3.8.1). On the chalkland soil at Andover, there were no consistent differences, but minimal tillage tended to show the lowest soil levels, whereas direct sowing and ploughing were similar. At Cirencester, the initial advantage to ploughing that was apparent in October 1998 was not maintained. At Biggleswade, there was some evidence of higher levels after ploughing than following minimal tillage in the wet autumn and winter of 2000/01, but no wheat crop was established here until the spring.

Table 3.8.1 The effect of establishment method on soil nitrogen levels (October 1998 – August 2001)

Sampling Date	**October 1998**	**November 1998**	**February 1999**	**November 2000**	**February 2001**	**August 2001**
Establishment Method	**Soil Mineral Nitrogen (kg N/ha 0-30cm depth)**					
	Andover					
Direct sowing	15	21	21	8	14	32
Minimal tillage	11	19	24	7	11	19
Plough / press	18	22	24	8	13	30
	Cirencester					
Direct sowing	56	35	19	40	36	23
Minimal tillage	58	35	17	39	33	25
Plough / press	72	39	15	36	35	22
	Biggleswade					
Direct sowing	22	19	10	8	15	9
Minimal tillage	23	19	10	6	11	6
Plough / press	25	19	11	12	19	6

4. Discussion

4.1 Establishment Method

At Andover, on the chalkland soil, minimal tillage was the highest-yielding and most profitable establishment method in all years, regardless of the seasonal conditions. In the first and fourth seasons, direct sowing was superior to ploughing. However in the middle two seasons, which had wetter autumns, ploughing resulted in a higher yield than direct sowing. In both of these years, plant populations in the direct-sown blocks were lower than for the other methods. In 2000/01, populations in the direct-sown were half those in the minimal tillage or ploughed blocks, and this was the only season where ploughing was more profitable than direct sowing.

On the medium loam at Cirencester, there were no significant yield differences between establishment methods except in 2000/01, when direct sowing was lower yielding than ploughing. Again this was a consequence of the wet autumn of 2000, although more due to greater competition from blackgrass than poor establishment alone. Direct sowing was therefore the most profitable technique in all years except 2001. Whilst ploughing gave a similar average yield to minimal tillage, it was slightly less profitable overall.

The heavy clay loam at Biggleswade saw the greatest change between years. In the first season, there were no significant differences between establishment methods, so direct was the most profitable. In the following two seasons, direct sowing was lower yielding and less cost-effective than the other two methods. Minimal tillage was the most profitable technique in 2000, and ploughing in 2001. The inability of the clay to dry under the chopped straw mulch severely reduced the establishment of the direct-sown blocks at Biggleswade, resulting in a crop that competed poorly with the high brome grass population. Though also present in the minimal tillage blocks, better crop competition resulted in less apparent yield loss. The consequences of failing to sow in the autumn were particularly severe with the non-inversion methods, as these appeared unsuited to establishing the spring wheat crop in 2001. It was the wet conditions that forced this change, so had an attempt been made to drill in the autumn the ploughed blocks were equally the only ones where this might have been possible.

Energy analysis shows that, on all three sites, plough and press used the most direct and indirect energy per hectare, and direct sowing the least. However, because lower yields were obtained with direct sowing in some seasons, minimal tillage had the lowest energy cost per tonne of grain at both Andover and Biggleswade. At Cirencester, direct sowing also tended to have the lowest energy cost tonne.

There were some differences in grain quality between establishment methods, but these were not always consistent between sites or seasons. However, with the exception of the first year at Cirencester, where specific weight differences were recorded it was direct sowing that produced lower values than either minimal tillage or ploughing. This was often associated with instances of lower yield due to inferior establishment or grass weed competition. The ability of winter wheat to compensate structurally for a 'poor start' was highlighted by the fact that direct sowing often gave equal or higher ear populations than the other establishment methods even where it had begun with a lower plant population.

In the first season, there was evidence at all locations of a higher initial take-all incidence after direct sowing than following ploughing. However in subsequent seasons, where differences were observed, take-all severity was generally higher after ploughing. The latter could be explained by reduced consolidation and the build up of a layer of straw residues in proximity to the roots. Interestingly, the incidence of eyespot was consistently lower after direct sowing than following the plough. In some, but not all, cases this could be due to the lower plant populations that tended to be achieved in the direct-sown blocks. Minimal tillage did not show the same advantage, and tended to have the highest levels of Fusarium.

Interactions between establishment method and root or stem base diseases are not unexpected and are likely to be complex. However, the same would appear to be true for the main foliar disease, with significantly lower levels of *S. tritici* present after direct sowing than after ploughing in most of the trials. Part of the reason for this could again be lower plant populations, although in some cases the disease differences lasted until July by which time crop densities (ear populations) were similar. It would certainly be wrong to assume that failing to cultivate increases the threat posed by *S. tritici*, or the need for additional expenditure to control it.

The presence of higher broad-leaved weed populations after ploughing than after direct sowing (and in some trials minimal tillage) was predictable but did not cause any specific problems. However, the difficulties posed by a build up of grass weeds (blackgrass and bromes) with repeated direct sowing, even within the 3-4 year period of this project, necessitated additional herbicide applications which might have been avoided under the ploughed system. The most effective establishment technique for grass weed control would inevitably have to take priority over any broad-leaved weed considerations.

Surprisingly, establishment method had little consistent effect on soil mineral nitrogen. Ploughing might have been expected to result in the highest levels in the autumn, but this was only apparent in the first season (autumn 1998) at Cirencester and (to a lesser extent) Andover, and in the third season (autumn 2000) at Biggleswade. Where there were differences, more often than not levels were lower in the minimal tillage than in the direct-sown. However, as the latter generally had lower plant populations and less biomass present than the other techniques, early uptake of nitrogen by the crop would have been less, leaving a larger proportion in the soil. The results do not indicate an automatic increase in the need for autumn-applied nitrogen fertiliser, for crops established in the presence of chopped straw by non-inversion methods compared to after ploughing.

4.2 Take-all Seed Treatment and its Interaction with Establishment Method

The largest yield benefits from the use of Latitude seed treatment were obtained in the first year of the project, in the second wheat situation. This was the only season where the take-all treatment was cost-effective for all establishment methods at Andover and Biggleswade. In the second year (third wheat), both locations gave an economic benefit only in the direct-sown blocks, and even this was small. Cirencester behaved differently, with cost-effective yield increases in the second and third wheat situations, but only with minimal tillage. This could in part be related to the 'break' crop that preceded the first wheat on each site *i.e.* in 1996/97, two seasons before the project started. At Andover and Biggleswade these were winter oats and set-aside respectively, but at Cirencester it was spring barley, which would have been least effective as a take-all break.

Whilst all three locations had their highest levels of take-all in the direct sown blocks in the first autumn, this was not the case subsequently, and the observed yield benefits for each establishment system, particularly at Andover, were not consistent with differences in the severity of take-all. However, the yield responses obtained in 1999 were associated with increases in thousand grain weight, wherever Latitude had been used.

4.3 The Effect of Number of Passes, and its Interaction with Other Factors

Reducing the number of core input passes from 7 (the control treatment) to 3 or 4 (as in the minimum pass) decreased yield at all three locations in 1999 and 2000. However, whilst the reductions at Andover and Cirencester were very similar in the two years, at Biggleswade the penalty was 10 times greater in 2000 than in 1999. In 2001, there was no benefit from the higher number of passes at Andover or Cirencester, although there was still a small yield increase in the spring wheat at Biggleswade. These responses were consistent with larger thousand grain weights in the multi pass control compared to the minimum pass treatments in 1999 and 2000, whereas in 2001 this effect was only observed at Cirencester and in the direct-sown blocks.

The main difference between the control and minimum pass systems (excluding the split nitrogen dose, which can be eliminated due to the lack of difference between the 4 and 3-pass systems) was the additional early (T1) and late (T3) fungicide applications. Although the 7-pass was also the only system that received an early plant growth regulator, with no lodging in any of the trials, and no obvious height or other effects, it is unlikely that this was the main cause of yield differences. Disease assessments in 1999 and 2000 confirmed significantly less *S. tritici* in the 7-pass at both Andover and Cirencester. In 2001, disease levels were low at both locations. Results from the small plot experiments taking place alongside these trials at Biggleswade and Andover also highlighted the lack of penalty from single-spray fungicide strategies in 2001 (see part ii).

At Andover, neither establishment method nor seed treatment had any effect on the yield response to the higher number of passes. At Cirencester and Biggleswade, the use of Latitude seed treatment resulted in a larger yield increase from the higher number of passes. At Biggleswade direct-sown blocks benefited more from the 7-pass system than minimal tillage or ploughing. This would suggest that, where the crop was disadvantaged by having a low plant population and strong competition from grass weeds, maintaining the health of those plants that were present was of particular importance.

Averaging the three establishment methods, none of the trials showed a benefit from the 4-pass husbandry system compared to the 3-pass. However, looking at them separately, at Andover and Biggleswade there was a tendency for the extra pass to have a negative effect on yield in the minimal tillage and direct-sown blocks, but a positive effect after ploughing. The only difference between the 4 and 3-pass systems was a split nitrogen application, which would imply that this was of little advantage despite the second-fourth wheat situation, and that any benefit was greater after ploughing.

Previous trials funded by HGCA and conducted by ARC (Project Report No. 255) as well as other work have shown the importance of an early nitrogen dose on second and subsequent wheats. However, in the minimum pass trials the application timing of the main (or single) nitrogen dose was deliberately brought forward, to minimise the impact of not applying an early split. In addition, all of the trials in reported in Project 255 were conducted in ploughed situations. The reason why there was an apparent greater benefit from splitting the nitrogen after ploughing is not entirely clear, but it is interesting to note that in the second and subsequent seasons of the project there was a tendency for take-all severity to be greatest after ploughing.

Although the 7-pass control gave the highest mean yields, differences in gross margin were relatively small. Indeed at Andover, the minimum pass systems gave the highest gross margins. When application and establishment costs were included, it was the 3-pass systems that gave the highest margins at all locations, indicating that the yield benefits resulting from the extra inputs were not sufficient to cover both the additional chemicals and the cost of the extra application passes.

Averaged over the three years, the highest margin combination on the light chalkland soil at Andover and on the heavy clay loam at Biggleswade was minimal tillage, without Latitude seed treatments and managed with the lowest number of passes. On the medium loam soil at Cirencester, it was direct sowing, again without Latitude seed treatment and managed with the lowest number of passes.

(Discussion headings 4.4-4.6 are based on establishment problems and solutions reported by Long Ashton Research Station, during the first three years of the project)

4.4 Management of Previous Crop Residues

There were no major crop residue problems with plough-based establishment, although it was more time consuming in land management and preparation prior to drilling than minimal tillage or direct sowing. Coping with trash is the most frequently cited problem with non-inversion establishment systems, especially if the straw from the previous crop has not been effectively chopped and spread. The most significant problem experienced was the uneven spread of chaff and chopped/unchopped straw behind the combine. This led to some "hair-pinning", which can hamper the drilling operation, and initially at least the locking up of nitrogen. "Toxins" from incorporated crop residues may have contributed to poor and patchy crop establishment. In the first year at Cirencester, initial establishment difficulties occurred as the required "intercrop" management had not taken place, and the trial was established into unchopped straw.

Solution: This was alleviated in subsequent years, and at the other sites, by ensuring a good straw chop and spread. This then allowed weeds and volunteers to grow during the intercrop periods that were sprayed off with glyphosate prior to drilling. This approach gave a more manageable straw/soil surface (=seedbed) in which to drill wheat. There are a range of options to mitigate against these problems including better straw chopping and chaff spreading, early post- harvest incorporation and, if necessary an additional pass either to spread the straw on the soil surface prior to incorporation or to facilitate further breakdown after initial incorporation. There were no apparent soil type interactions.

4.5 Slugs

The presence of trash in the seeding zone increases slug problems, and it is well documented that slug populations are much higher in reduced tillage systems. Within this project, slugs and associated problems were more apparent on the heavy-land at Biggleswade than at other sites. Creating a stale seedbed is hugely beneficial to reducing weed pressure that can occur in the crop post-drilling, but it also creates a green bridge that benefits slug populations. A surface application of molluscicide is likely to be more effective than slug pellets mixed with the seed in most conditions. The best approach is good seed placement in a good seedbed, with good consolidation. Consolidation is absolutely essential in non-plough systems, as is the effective closure of the seeding slot in direct-drill systems. In the second season at Biggleswade, weather limitations meant that a final roll after drilling was not possible. Although slug pellets had been drilled with the seed, the open drill slot provided an ideal environment for slugs to crawl along the slot and burrow out seed prior to emergence.

Solutions: Slugs can be dealt with using both physical and chemical options or, indeed a combination of both. Experience in these experiments, with the exception of the situation mentioned above, relied heavily on the former for effective control. Accurate placement of seed at 4cm depth, achievable in all systems with the Vaderstad Rapid drill, gave most effective protection against slugs at all sites and, as a consequence, minimum molluscicide treatments were required.

4.6 Weeds

Dealing with weeds is intrinsically linked with cultivations. There are a number of options depending on the crop, time of sowing and crop rotation. Ideally the inter-crop period is good for reducing the seed bank but stubble cleaning sprays and pre-harvest desiccants also help.

Whilst all of these sites had some grass weeds, it was only the lack of cultivation in the direct-sown blocks at Biggleswade which exacerbated the problem (in this case with brome grasses). Although not experienced in these relatively small-scale replicated trials, the increased work rates achieved by reduced tillage systems can give rise to another difficulty on larger farms. The crop is established across a broad acreage in a limited time period and consequently both the crop and the weeds are at similar developmental stages. Often this puts pressure on the herbicide sprays that are required during November, since there may be insufficient spray days at this time to get all crops treated. One option is to use a pre-emergence residual herbicide on a proportion of the acreage. This needs to be a planned operation since it may mean that no further intervention with the sprayer is required until spring and hence a BYDV seed treatment should be considered.

Solution: whilst there is no "blueprint solution" to weed problems, especially grass weeds, ploughing buries weed seed and can reduce grass weeds by up to 63%. Reduced cultivations alone will increase grass weeds, but good management using knowledge of weed seed distribution in soils and weed germination periods are keys to strategic decision-making for both weed control and minimising resistance development. Weed control begins pre-harvest and inter crop management is the key to success. Stale seedbeds are most effective and when combined with delayed drilling and crop rotation allows the use of different herbicide chemistry. Planning is essential: prioritise control outside the crop – pre-harvest opportunity, stale seedbeds, non-selective herbicides, weed control prior to crop establishment; use a programmed approach – stale seedbeds/drilling date/pre-emergence and mixtures or sequences with different chemistry.

5. Conclusions and Implications

The primary aim of this project was to reduce the unit costs of winter wheat production without significantly reducing output, by means of lowering the costs of establishment and/or application of husbandry inputs. A key objective was also to determine whether savings made during establishment then in any way affected the success of a minimum pass husbandry approach. In order to provide the sternest possible test, the trials were conducted in consecutive wheat crops, located in exactly the same place for the duration of the project, with all straw residues chopped and returned, and using a disease susceptible variety. In addition soil types ranging from a light chalkland soil to a heavy chalky clay loam were included in the three sites.

Over the project as a whole, minimal tillage and direct-sown establishment methods proved capable of delivering equal or higher yields than a conventional plough-based approach, on all soil types, despite the presence of chopped straw residues. However, there were some important differences between sites and seasons:

- On the light chalkland soil at Andover, minimal tillage produced the highest margins in all four seasons, averaging £26/ha more profit than direct sowing, and £70/ha more profit than ploughing
- On the medium loam at Cirencester, direct sowing was more cost-effective than the other methods in three out of four seasons, averaging £19/ha more profit than minimal tillage and £28/ha more than ploughing
- On the heavy clay loam at Biggleswade, no single establishment method performed best in all seasons. Direct sowing was the most cost-effective in the first season, minimal tillage in the second and ploughing in the third. Direct sowing performed poorly in the second and third years, and overall was £49/ha less profitable than ploughing, and £56/ha less profitable than minimal tillage
- The greatest advantage to ploughing over direct sowing occurred on the medium and heavy soils in 2000/01, which was severely affected by the wet autumn/winter of 2000. Establishment of the winter crop at Cirencester and delayed spring wheat at Biggleswade was particularly poor in the direct-sown blocks
- With the exception of the light soil at Andover, which was free from ‘difficult’ grass weeds, resistant blackgrass (at Cirencester) and a high population of brome grasses (at Biggleswade) quickly emerged as limiting factors. This contributed to the problems encountered in the direct-sown blocks, especially at Biggleswade where ploughing was the most effective method of grass weed control

The main conclusion from this is that on chalkland soils with no difficult grass weeds, minimal tillage should provide a sustainable basis for reducing establishment costs. However, a more flexible approach is needed on medium or heavy soils, where very wet soil conditions under chopped straw may reduce the success of non-inversion methods. Resistant or high populations of grass weeds are likely to compound this problem.

There was little evidence from this project that minimal tillage or direct sowing increase the risk of take-all, or the likelihood of a cost-effective response to a seed treatment, even in the presence of chopped straw. In fact, there was an indication that as the project progressed take-all severity was highest in the ploughed blocks, although none of the establishment methods showed substantial benefits from Latitude after the first season.

With the exception of 2001, when disease pressure was low due to mainly dry weather from May onwards, both the 3 and 4 'minimum' pass strategies gave yield reductions compared to the 7 pass control treatment. This was associated with higher levels of foliar disease in both 1999 and 2000. However, in some cases the yield penalties were not sufficient to outweigh the savings in chemical and applications costs, and overall the lowest number of passes was the most cost-effective at all locations.

The average increase in margin as a result of adopting the minimum pass approach was £46/ha at Andover, £21/ha at Cirencester and £20/ha at Biggleswade. One reason for the greater improvement at Andover was the much smaller yield penalty experienced with only a single fungicide in the wet spring of 2000. This was also the case in the minimum pass fungicide experiments that accompanied these trials. A succession of wet, high-disease pressure seasons such as 2000 could radically alter the relative economics of low and high pass number systems. Whilst these trials were conducted on the disease-susceptible variety Consort, in practice a more resistant variety should be selected if minimum pass husbandry is to be used.

There was little evidence of a benefit from splitting the nitrogen dose, as in the 4-pass system, suggesting that this pass could more readily be omitted even in non-first wheats. However, there are several considerations:

- In these trials, the timing of the main (or single) dose nitrogen application was brought forward to reduce the risk of uptake decreasing as take-all damage to the roots increased
- There was still a benefit in some of the ploughed situations, possibly linked to greater take-all severity
- In a farm situation it may be undesirable to try to apply all of the nitrogen to a crop in one large dose

There was only one circumstance where adopting a lower-cost establishment method reduced the success of minimum pass husbandry. This was on the heavy land site at Biggleswade, where the poorly established direct-sown blocks appeared to benefit more from the higher number of passes. Indeed, there was evidence of lower levels of foliar and stem-base disease with direct sowing compared to ploughing (possibly linked to other factors), as well as less benefit from split nitrogen, both of which should facilitate a minimum pass approach. The combination of minimal tillage and minimum pass husbandry improved overall margin by an average of £120/ha on the chalk soil at Andover, and £52/ha on the clay loam at Biggleswade, compared to establishment with the plough followed by the 7-pass control treatment. On the medium loam soil at Cirencester, the best combination of direct sowing and minimum pass gave a more modest average improvement of £36/ha.

6.1 Acknowledgements

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6.2 References

Knight SM (2001). *Managing Early-Drilled Second Wheats to Minimise the Impact of Take-all. HGCA Project Report No. 255.* Home-Grown Cereals Authority, London

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7. Appendices

Appendix A Inputs Applied to each Trial in 1998/99, 1999/00 and 2000/01

Table 7.1 Inputs Applied to Andover Trial in 1998/99

	Pass Systems		
Input(s) Applied (l/ha)	**3**	**4**	**7**
Panther 1.0 + IPU 1.0 plus cypermethrin 0.25 on 17 November	yes	yes	yes
First nitrogen dose on 5 March (kg N/ha)	no	80	80
Main nitrogen dose on 1 April (kg N/ha)	200	120	120
5C Cycocel 2.5 at GS30	no	no	yes
T1 Opus 0.5 + Bravo 0.5 at GS32	no	no	yes
T2 Amistar 0.75 + Opus 0.5, plus Starane 0.6 at GS39	yes	yes	yes
T3 Amistar 0.25 at GS65	no	no	yes

Sting 2.0 l/ha applied pre-sowing to direct sowing and minimal tillage blocks only

Table 7.2 Inputs Applied to Cirencester Trial in 1998/99

	Pass Systems		
Input(s) Applied (l/ha)	**3**	**4**	**7**
Hawk 2.5 + Panther 1.0 plus cypermethrin 0.25 in autumn	yes	yes	yes
First nitrogen dose in early March (kg N/ha)	no	40	40
Main nitrogen dose in early April (kg N/ha)	200	160	160
5C Cycocel 1.75 at GS31	no	no	yes
T1 Opus 0.5 + Bravo 0.5 at GS32	no	no	yes
T2 Landmark 0.75, plus Topik 0.125 + oil, at GS39	yes	yes	yes
T3 Amistar 0.5 + Folicur 0.5 at GS65	no	no	yes

Sting 1.5 l/ha applied pre-sowing to all blocks

Table 7.3 Inputs Applied to Biggleswade Trial in 1998/99

	Pass Systems		
Input(s) Applied (l/ha)	**3**	**4**	**7**
Lexus Class 60g plus deltamethrin 0.20 on 23 February	yes	yes	yes
First nitrogen dose on 17 March (kg N/ha)	no	45	45
Main nitrogen dose on 16 April (kg N/ha)	195	150	150
5C Cycocel 2.5 at GS30	no	no	yes
T1 Opus 0.5 + Bravo 0.5, plus Ally 30g, at GS32	no	no	yes
T2 Amistar 0.75 + Opus 0.5 at GS39	yes	yes	yes
T3 Amistar 0.25 at GS65	no	no	yes

Sting 2.0 l/ha applied pre-sowing to all blocks

Table 7.4 Inputs Applied to Andover Trial in 1999/00

Input(s) Applied (l/ha)	Pass Systems		
	3	4	7
Javelin 1.0 + IPU 2.0 plus Hallmark 0.10 on 18 November	yes	yes	yes
First nitrogen dose on 7 March (kg N/ha)	no	80	80
Main nitrogen dose on 14 April (kg N/ha)	200	120	120
5C Cycocel 2.5 at GS30	no	no	yes
T1 Opus 0.5 + Bravo 0.5 at GS32	no	no	yes
T2 Amistar 0.75 + Opus 0.5 at GS39	yes	yes	yes
T3 Amistar 0.5 at GS65	no	no	yes

Sting 2.0 l/ha applied pre-sowing to direct sowing and minimal tillage blocks only

Table 7.5 Inputs Applied to Cirencester Trial in 1999/00

Input(s) Applied (l/ha)	Pass Systems		
	3 (5)	4 (6)	7 (9)
Avadex 22.5 kg/ha	yes	yes	yes
Amazon 1.0 + Lexus 20g plus cypermethrin 0.25 on 15 November	yes	yes	yes
First nitrogen dose in early March (kg N/ha)	no	40	40
Main nitrogen dose on 7 April (kg N/ha)	200	160	160
Dagger 2.0 + IPU 3.0 on 31 March	yes	yes	yes
5C Cycocel 1.7 at GS30	no	no	yes
T1 Amistar 0.25 + Opus 0.25 at GS32	no	no	yes
T2 Amistar 0.75 + Opus 0.25 at GS39	yes	yes	yes
T3 Opus 0.25 at GS65	no	no	yes

Sting 1.5 l/ha applied pre-sowing to all blocks   Figures in brackets are actual no. of passes for each system

Table 7.6 Inputs Applied to Biggleswade Trial in 1999/00

Input(s) Applied (l/ha)	Pass Systems		
	3 (5)	4 (6)	7 (9)
Avadex 22.5 kg/ha	yes	yes	yes
IPU 5.0 + Ardent 2.5 plus deltamethrin 0.2 on 4 November	yes	yes	yes
First nitrogen dose on 13 March (kg N/ha)	no	40	40
Main nitrogen dose on 10 April (kg N/ha)	200	160	160
Monitor 25g + tallow-amine 0.5	yes	yes	yes
5C Cycocel 2.5 at GS30	no	no	yes
T1 Opus 0.5 + Bravo 0.5 at GS32	no	no	yes
T2 Amistar 0.75 + Opus 0.5 + Tern 0.25 at GS39	yes	yes	yes
T3 Amistar 0.25, plus deltamethrin 0.25, at GS65	no	no	yes

Sting 2.0 l/ha applied pre-sowing to all blocks

Table 7.7 Inputs Applied to Andover Trial in 2000/01

Input(s) Applied (l/ha)	Pass Systems		
	3 (4)	4 (5)	7 (7)
methiocarb slug pellets 5.5 kg on 15 November	yes	yes	yes
Javelin 1.0 + IPU 2.0 plus Hallmark 0.1 on 16 January	yes	yes	yes
First nitrogen dose on 3 April (kg N/ha)	no	80	80
Main nitrogen dose on 17 April (kg N/ha)	200	120	120
T1 Opus 0.5 + Bravo 0.5 at GS32	no	no	yes
T2 Amistar 0.75 + Opus 0.5 at GS39	yes	yes	yes
T3 Amistar 0.5 at GS65	no	no	yes

Sting 2.0 l/ha applied pre-sowing to direct sowing and minimal tillage blocks only

Table 7.8 Inputs Applied to Cirencester Trial in 2000/01

Input(s) Applied (l/ha)	Pass Systems		
	3 (5)	4 (6)	7 (9)
Stomp 3.0 + Lexus 20g on 10 November	yes	yes	yes
First nitrogen dose in mid March (kg N/ha)	no	40	40
Main nitrogen dose on 19 April (kg N/ha)	200	160	160
Topik 0.125 + IPU 2.0 + oil on 2 May	yes	yes	yes
5C Cycocel 1.5 at GS31	no	no	yes
T1 Twist 0.5 + Opus 0.5 at GS32	no	no	yes
T2 Twist 1.0 + Opus 0.5 at GS39	yes	yes	yes
T3 Amistar 0.25 at GS65	no	no	yes
Dursban 4 (chlorpyrifos) 1.0 on 13 June	yes	yes	yes

Roundup Biactive 1.5 l/ha applied pre-sowing to all blocks

Table 7.9 Inputs Applied to Biggleswade Spring Wheat Trial in 2000/01

Input(s) Applied (l/ha)	Pass Systems		
	3 (3)	4 (4)	7 (5)
Oxytril CM 1.5 + Starane 2 0.75 on 4 June	yes	yes	yes
First nitrogen dose on 11 May (kg N/ha)	no	75	75
Second nitrogen dose on 4 June (kg N/ha)	150	75	75
T1 Amistar 0.25 + Folicur 0.25 at GS31	no	no	yes
T2 Amistar 0.25 + Folicur 0.25, plus Aphox 280g, at GS55	yes	yes	yes

Sting 4.0 l/ha applied in October to all blocks, followed by 5.5 l/ha Gramoxone 100 pre-sowing in May

Appendix B Tractor Power, Implement Widths and Forward Speeds

Table 7.10 Ploughing and pressing

Plough and press		Tractor (hp)	Width (m)	Speed (km/hr)
Andover	Plough + press	130	2.00	8.0
Biggleswade	Plough	155	1.83	5.8
	Press	155	4.50	5.8
Cirencester	Plough + press	120	2.00	6.0

*All assuming 75% of tractor power is used except pressing at Biggleswade (65%)

Table 7.11 Minimal Tillage

Disc / press		Tractor (hp)	Width (m)	Speed (km/hr)
Andover		170	3.75	12.0
Biggleswade		125	3.50	6.5
Cirencester		150	3.00	7.0

*All assuming 75% of tractor power is used

Table 7.12 Drilling

All 150hp tractor, 3m wide drill, 7.5km/hr forward speed

Differences in soil type and cultivations will effect the percentage power used (%)

Drilling		Direct	Min till	Plough
Andover		75%	70%	65%
Biggleswade		85%	80%	75%
Cirencester		80%	75%	70%

Minimum Pass Fungicide Strategies for Winter Wheat

1. Introduction

In order to implement a successful minimum pass husbandry policy, a key requirement is to have an effective disease control strategy that does not require frequent trips through the crop to apply fungicides. At present, a typical husbandry programme may include up to four spray application passes for disease control. Whilst some of these may be combined with other treatments, often they will consist only of fungicides. The ultimate minimum pass fungicide strategy would consist of only one spray, although a reduction from three or four down to two passes may in some circumstances be all that is desired.

There are many important considerations for the development of a minimum pass fungicide strategy, several of which were highlighted by previous HGCA-funded work on winter wheat husbandry systems (Project 167):

- The key limitation is number of passes through the crop, not the amount of fungicide used. A single-spray strategy is likely to include higher level of input than any one treatment from a multiple spray programme
- The objective of a single-spray strategy is to match or exceed the margin over cost of a multiple-spray programme, not necessarily to produce the same yield or disease control
- Both the cost of the fungicide chemicals and the application costs should be considered when comparing single and multiple spray strategies
- Application timing is likely to be crucial where only a single fungicide spray is to be applied. Clearly this would need to be targeted at protecting the upper leaves as these make the greatest contribution to yield
- Whilst single-spray strategies may present less risk on disease resistant varieties, their limitations should be explored on varieties which are disease susceptible and highly yield-responsive to the use of fungicides
- A minimum pass approach may be more applicable in drier regions, where responses to fungicides have historically been lower.

The aim of this section of the project was to examine single-spray fungicide strategies, and to compare them for yield, margin and disease control with a typical three-spray control programme. The variety chosen was Consort, which is susceptible to both *Septoria tritici* and brown rust. In addition, trials were located in 'wet' (high *Septoria* / low brown rust risk) and 'dry' (low *Septoria* / high brown rust risk) areas. The trials did not encompass yellow rust, as this would effectively preclude a minimum pass strategy on susceptible varieties in high-risk seasons or locations, nor did they specifically target mildew. Finally, Project 167 speculated that the introduction of strobilurins, with their persistent activity, would strengthen the case for a single-spray strategy. Therefore, strobilurins (mixed with triazoles) formed the basis of the strategies evaluated here. However, since these trials were completed, strobilurin-resistant isolates of *S. tritici* have been discovered (see later note).

2. Materials and Methods

Twelve single-spray fungicide treatments were compared with a three-spray control programme on the winter wheat variety Consort, sown in late September or early October at Andover in Hampshire and at Biggleswade in Bedfordshire. The trials were conducted over three seasons, in 1998/99, 1999/00, and 2000/01.

Site characteristics for the two locations were:

Andover, Hampshire	Soil type Andover series chalkland soil
	Average annual rainfall 735 mm
	Typical seed rates 300-350 seeds/m^2
Biggleswade, Bedfordshire	Soil type Cannamore series calcareous clay / clay loam
	Average annual rainfall 570 mm
	Typical seed rates 350-400 seeds/m^2

The fungicides that were used in the trials were as follows:
In all seasons – Amistar (250 g/l azoxystrobin), Opus (125 g/l epoxiconazole) and Bravo 500 (500 g/l chlorothalonil)
In 1998/99 and 1999/00 only – Landmark (125 g/l epoxiconazole + 125 g/l kresoxim-methyl)
In 2000/01 only – Twist (125 g/l trifloxystrobin)

Single-spray treatments were applied at three timings, GS32 (when leaf 3 was two-third or three-quarters emerged), GS37 (when the flag leaf blade was visible) and GS39-45 (between when the flag leaf was fully emerged and the boots had started to swell). Calendar dates varied with season, but were typically around 25th April, 15th May and 25th May respectively. The three-spray programme consisted of separate applications at GS32, GS39-45 and GS65 (typically around 15th June).

At each timing, both 'full' (1.0 l/ha) and 'half' (0.5 l/ha) dose rates of the strobilurin components (Amistar, and Landmark or Twist) were evaluated as single sprays. In the case of Twist, the 'full' dose was considered to be 1.5 l./ha (equivalent to 75% of the maximum approved dose), and the half rate 0.75 l/ha (equivalent to 37.5% of the maximum approved dose). Twist and Amistar were partnered by a half dose of the triazole (Opus), but in the case of Landmark, as a pre-formulated mixture, the dose of triazole was the same as the dose of strobilurin.

Important Note. These trials were conducted prior to the discovery of strobilurin-resistant isolates of *Septoria tritici*. The treatments that were included were not intended to, and therefore do not necessarily, represent best current practice for the effective use of strobilurins or the control of *S. tritici*.

The full list of treatments is shown in Table 2.1:

Table 2.1. Treatments included in the minimum pass fungicide strategy evaluation trials

GS32	GS37	GS39-45	GS65
Three-spray control			
Opus 0.5 + Bravo 0.5	-	Amistar 0.75 + Opus 0.5	Amistar 0.25
Single-spray treatments			
Amistar 1.0 + Opus 0.5	-	-	-
Amistar 0.5 + Opus 0.5	-	-	-
-	Amistar 1.0 + Opus 0.5	-	-
-	Amistar 0.5 + Opus 0.5	-	-
-	-	Amistar 1.0 + Opus 0.5	-
-	-	Amistar 0.5 + Opus 0.5	-
Landmark 1.0 or Twist 1.5 + Opus 0.5	-	-	-
Landmark 0.5 or Twist 0.75 + Opus 0.5	-	-	-
-	Landmark 1.0 or Twist 1.5 + Opus 0.5	-	-
-	Landmark 0.5 or Twist 0.75 + Opus 0.5	-	-
-	-	Landmark 1.0 or Twist 1.5 + Opus 0.5	-
-	-	Landmark 0.5 or Twist 0.75 + Opus 0.5	-

All spray treatments were applied in 200 l/ha water volume using 02-F110 conventional flat fan nozzles at 2 bar pressure.

The incidence of disease (*Septoria tritici* at both locations, and brown rust at Biggleswade only), and the proportion of the leaf area remaining green, was assessed at intervals from GS39-45 through to GS75 on the top three final leaves. In each case the assessment was based on the mean % diseased (or green) leaf area of ten randomly selected plants per plot.

3. Results

The results from the two locations over three seasons are divided into the following areas:

3.1 Grain Yield

3.2 Economic analysis

3.3 Disease Levels

3.4 Grain Quality

3.1 Effect of Single-Spray Fungicide Strategies on Grain Yield (1999-2001)

Grain yields for the full and half-rate single-spray strategies are shown as t/ha and as a % of the 3-spray control programme, which was: GS32 Opus 0.5 + Bravo 0.5
GS39 Amistar 0.75 + Opus 0.5
GS65 Amistar 0.25

At Andover and Biggleswade, disease pressure and yield penalties were highest in 2000, and lowest in 2001. In 2000, the single-spray treatments were frequently more than 20% lower yielding than the 3-spray control, whereas in 2001 the largest penalty was only 3%. Yields of the control treatment were more stable on the heavy land at Biggleswade (range 9.2-9.8 t/ha) than on the lighter land at Andover (range 7.6-9.6 t/ha). The individual trial yields, and the 3-year means for each location, are shown in Tables 3.1.1-3.1.8.

Andover

In 1999, the yield penalty from a single fungicide treatment compared to the three-spray control ranged from 0-7 % (Table 3.1.1). Neither timing nor dose rate of the single sprays had any consistent effect, although the optimum timing was GS37 for all treatments except half-rate Amistar.

Table 3.1.1 Effect of fungicide strategy on grain yield (Andover, 1999)

	Grain Yield (t/ha and % 3-spray control)					
Timing of Single Spray	**GS32**		**GS37**		**GS39-45**	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Landmark 0.5	7.13	94	7.26	96	7.24	96
Landmark 1.0	7.35	97	7.59	100	7.05	93
Amistar 0.5 + Opus 0.5	7.45	99	7.07	94	7.34	97
Amistar 1.0 + Opus 0.5	7.13	94	7.36	97	7.17	95
3-Spray Control (GS32,39,65)	7.56 t/ha = 100%		LSD (p = 0.05) = 0.50		CV 4.1%	

Under much higher disease pressure, the yield penalty from a single fungicide in 2000 ranged from 4-32% (Table 3.1.2). Here, timing of the single spray had a substantial impact, with GS39-45 giving a significantly higher yield than GS37 or GS32 regardless of the treatment applied. The full dose rates were also consistently superior to the half rates at each timing, although the differences were only significant for Landmark. Amistar + Opus was higher yielding than Landmark at half rates or at the earliest of the application timings.

Table 3.1.2 Effect of fungicide strategy on grain yield (Andover, 2000)

	Grain Yield (t/ha and % 3-spray control)					
Timing of Single Spray	**GS32**		**GS37**		**GS39-45**	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Landmark 0.5	6.52	68	6.81	71	8.29	86
Landmark 1.0	6.99	73	7.73	80	9.18	95
Amistar 0.5 + Opus 0.5	7.41	77	7.42	77	8.94	93
Amistar 1.0 + Opus 0.5	7.80	81	7.83	82	9.24	96
3-Spray Control (GS32,39,65)	9.61 t/ha = 100%		LSD (p = 0.05) = 0.49		CV 3.6%	

In 2001, with low disease pressure there was no yield penalty with any of the single spray treatments, and neither timing, dose rates or choice of fungicide had any significant effect on yield (Table 3.1.3).

Table 3.1.3 Effect of fungicide strategy on grain yield (Andover, 2001)

	Grain Yield (t/ha and % 3-spray control)					
Timing of Single Spray	**GS32**		**GS37**		**GS39-45**	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Twist 0.75 + Opus 0.5	8.97	99	9.06	100	9.14	101
Twist 1.50 + Opus 0.5	9.39	103	9.35	103	9.17	101
Amistar 0.5 + Opus 0.5	9.11	100	9.15	101	9.04	99
Amistar 1.0 + Opus 0.5	8.92	98	9.18	101	8.98	99
3-Spray Control (GS32,39,65)	9.09 t/ha = 100%		LSD (p = 0.05) = 0.41		CV 2.7%	

Averaged over the three years, the optimum timing for a single spray at Andover was GS39-45 (Table 3.1.4)

Table 3.1.4 Effect of fungicide strategy on grain yield (Andover, 3 year mean)

	Grain Yield (t/ha and % 3-spray control)					
Timing of Single Spray	**GS32**		**GS37**		**GS39-45**	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Amistar 0.5 + Opus 0.5	7.99	92	7.88	90	8.44	96
Amistar 1.0 + Opus 0.5	7.95	91	8.12	93	8.46	97
3-Spray Control (GS32,39,65)	8.75 t/ha = 100%					

Biggleswade

The yield penalty from a single fungicide treatment at Biggleswade in 1999 ranged from 2-8 % (Table 3.1.5). Whilst there were no significant differences between single sprays, the optimum timing for the full dose rates appeared to be GS39-45. When applied at this timing, half-rates were significantly lower yielding than the three-spray control, but full rates were not.

Table 3.1.5 Effect of fungicide strategy on grain yield (Biggleswade, 1999)

	Grain Yield (t/ha and % 3-spray control)					
Timing of Single Spray	**GS32**		**GS37**		**GS39-45**	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Landmark 0.5	8.66	94	8.58	93	8.42	92
Landmark 1.0	8.62	94	8.50	92	9.05	98
Amistar 0.5 + Opus 0.5	8.82	96	8.53	93	8.53	93
Amistar 1.0 + Opus 0.5	8.59	93	8.93	97	9.00	98
3-Spray Control (GS32,39,65)	9.20 t/ha = 100%		LSD (p = 0.05) = 0.64		CV 4.4%	

As at Andover, there were large yield penalties as a result of applying only a single fungicide in 2000, which ranged from 10-24% (Table 3.1.6). Unlike at Andover, the optimum timing appeared to be GS37, and the yield advantage of the full dose rates compared to the half rates was only significant at the GS39-45 timing. Amistar + Opus was generally superior to Landmark at the same timing, but differences were not significant.

Table 3.1.6 Effect of fungicide strategy on grain yield (Biggleswade, 2000)

	Grain Yield (t/ha and % 3-spray control)					
Timing of Single Spray	**GS32**		**GS37**		**GS39-45**	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Landmark 0.5	7.07	76	7.84	84	7.13	76
Landmark 1.0	7.42	79	8.29	88	7.81	83
Amistar 0.5 + Opus 0.5	7.34	78	8.14	87	7.42	79
Amistar 1.0 + Opus 0.5	7.23	77	8.42	90	7.97	85
3-Spray Control (GS32,39,65)	9.38 t/ha = 100%		LSD (p = 0.05) = 0.53		CV 4.0%	

In 2001, yield penalties from the single spray treatments did not exceed 3% and were not significant (Table 3.1.7). Neither timing nor dose rate had any consistent effects, but at GS39-45 Amistar + Opus compared more favourably with the three-spray control than Twist + Opus.

Table 3.1.7 Effect of fungicide strategy on grain yield (Biggleswade, 2001)

Timing of Single Spray	Grain Yield (t/ha and % 3-spray control)					
	GS32		GS37		GS39-45	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Twist 0.75 + Opus 0.5	9.54	98	9.61	98	9.49	97
Twist 1.50 + Opus 0.5	9.74	100	9.58	98	9.56	98
Amistar 0.5 + Opus 0.5	9.48	97	9.65	99	9.75	100
Amistar 1.0 + Opus 0.5	9.61	98	9.47	97	9.79	100
3-Spray Control (GS32,39,65)	9.78 t/ha = 100%		LSD (p = 0.05) = 0.33		CV 2.1%	

Averaged over the three years, GS37 was the optimum timing at Biggleswade, and the advantage to the full dose rate increased with later application timing (Table 3.1.8).

Table 3.1.8 Effect of fungicide strategy on grain yield (Biggleswade, 3 year mean)

Timing of Single Spray	Grain Yield (t/ha and % 3-spray control)					
	GS32		GS37		GS39-45	
Treatment (l/ha)	**t/ha**	**%**	**t/ha**	**%**	**t/ha**	**%**
Amistar 0.5 + Opus 0.5	8.55	90	8.77	93	8.57	91
Amistar 1.0 + Opus 0.5	8.48	90	8.94	95	8.92	94
3-Spray Control (GS32,39,65)	9.45 t/ha = 100%					

3.2 Effect of Single-Spray Fungicide Strategies on Margin (1999-2001)

The effect of fungicide spray strategy on margin (£/ha) relative to the three-spray control is shown in Tables 3.2.1-3.2.4. This has been calculated by subtracting the reduction in output (yield x grain price) from the saving in fungicide cost. Negative values mean that the single-spray strategy was less cost-effective than the three-spray, and positive values mean it was more cost-effective. The first table in each pair is based on the cost of the chemicals alone, whereas the second includes a value for application costs. The prices/costs used are: wheat £60/t, Amistar £28/litre, Opus £22/litre, Bravo £4/litre, and applications at £7/ha for each pass.

Andover

Ignoring application costs, in 2000 all of the single spray treatments lost money compared to the three-spray control, although when applied at GS39-45 there was only a small reduction in profitability (Table 3.2.1). By contrast, in 2001 all of the single sprays were more cost-effective than the three-spray, with the half-rate application at GS37 the most profitable. In 1999, half-rate single applications at GS32 or GS39-45 were more cost-effective than the three-spray, but others showed no advantage.

Table 3.2.1 Effect of fungicide strategy on margin (Andover, 1999-2001). Excluding application costs

	Increase (+) or Decrease (-) in Margin (£/ha) compared to 3-spray control					
Timing	**GS32**		**GS37**		**GS39-45**	
Fungicide Treatment	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5
1999	+20	-13	-2	+1	+14	-10
2000	-105	-96	-104	-94	-13	-9
2001	+28	+3	+31	+18	+24	+6
3 Year	-19	-35	-25	-25	+8	-4

If application costs are included, the single sprays at GS39-45 become marginally more profitable than the three-spray even in 2000, and all of the single sprays in 1999 are at least as cost-effective as the three-spray.

Table 3.2.2 Effect of fungicide strategy on margin (Andover, 1999-2001). Including application costs

	Increase (+) or Decrease (-) in Margin (£/ha) compared to 3-spray control					
Timing	**GS32**		**GS37**		**GS39-45**	
Fungicide Treatment	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5
1999	+34	+1	+12	+15	+28	+4
2000	-91	-82	-90	-80	+1	+5
2001	+42	+17	+45	+32	+38	+20
3 Year	-5	-21	-11	-11	+22	+10

Biggleswade

As at Andover, all of the single-spray strategies were less cost-effective than the three-spray control in 2000 (Table 3.2.3). In 1999, the full dose treatment at GS32 and half-dose treatments at GS37 and GS39-45 were also less cost-effective. However, in 2001, only the full dose single spray at GS37 was marginally less profitable than the three-spray.

Table 3.2.3 Effect of fungicide strategy on margin (Biggleswade, 1999-2001). Excluding application costs

	Increase (+) or Decrease (-) in Margin (£/ha) compared to 3-spray control					
Timing	**GS32**		**GS37**		**GS39-45**	
Fungicide Treatment	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5
1999	+4	-24	-13	-3	-13	+1
2000	-95	-116	-47	-45	-91	-72
2001	+9	+3	+19	-6	+25	+14
3 Year	-27	-46	-14	-18	-26	-19

With application costs included, all of the single spray strategies still lost money in 2000 (Table 3.2.4). In 2001, all the single sprays were now more cost-effective than the three-spray, with the half-rate at GS39 best. In addition, in 1999 only the full-rate single spray at GS32 was now less profitable than the three-spray.

Table 3.2.4 Effect of fungicide strategy on margin (Biggleswade, 1999-2001). Including application costs

	Increase (+) or Decrease (-) in Margin (£/ha) compared to 3-spray control					
Timing	**GS32**		**GS37**		**GS39-45**	
Fungicide Treatment	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5
1999	+18	-10	+1	+11	+1	+15
2000	-81	-102	-33	-31	-77	-58
2001	+23	+17	+33	+8	+39	+28
3 Year	-13	-32	0	-4	-12	-5

3.3 Effect of Single-Spray Fungicide Strategies on Disease Control (1999-2001)

As indicated earlier, disease pressure at both locations was highest in 2000 and lowest in 2001. The incidence of *S. tritici* was generally higher at Andover than at Biggleswade, especially in 1999, but yield penalties from the single-spray strategies were similar, partly due to the incidence of brown rust at Biggleswade (notably in 2000). Disease levels were assessed at intervals during the growing season, and on several leaf layers, but the most consistent data was obtained from leaf 2 at milky ripe in early July. This is shown in Tables 3.3.1-3.3.6.

Andover

In 1999, all of the single-spray treatments had substantially more *S. tritici* on leaf 2 than the three-spray control (Table 3.3.1). Applications at GS32 had the highest levels, and there was no consistent benefit from the full dose rates compared to the half rates except at GS39-45.

Table 3.3.1 Effect of fungicide strategy on disease control (Andover, 1999)

Treatment	**% *S. tritici* on leaf 2 at GS75**			
(l/ha) Spray Timing	**GS32**	**GS37**	**GS39-45**	**3-Spray**
Landmark 0.5	72	43	50	12
Landmark 1.0	63	31	41	
Amistar 0.5 + Opus 0.5	78	19	45	
Amistar 1.0 + Opus 0.5	83	27	34	

None of the single sprays matched the three-spray for disease control in 2000 either (Table 3.3.2). However, the GS39-45 timing was the most effective at controlling *S. tritici* on leaf 2, particularly with Landmark. With one exception, all of the single sprays gave better disease control at full rates than at half rates.

Table 3.3.2 Effect of fungicide strategy on disease control (Andover, 2000)

Treatment	**% *S. tritici* on leaf 2 at GS75**			
(l/ha) Spray Timing	**GS32**	**GS37**	**GS39-45**	**3-Spray**
Landmark 0.5	61	70	12	2.0
Landmark 1.0	34	24	13	
Amistar 0.5 + Opus 0.5	32	29	27	
Amistar 1.0 + Opus 0.5	17	17	10	

In 2001, the incidence of *S. tritici* on leaf 2 was substantially lower in all of the single-spray treatments, with only the GS32 applications failing to reduce levels to less than 3% (Table 3.3.3). Overall the GS39-45 timing was again the most effective at controlling the disease on leaf 2.

Table 3.3.3 Effect of fungicide strategy on disease control (Andover, 2001)

Treatment (l/ha) Spray Timing	% *S. tritici* on leaf 2 at GS75			
	GS32	**GS37**	**GS39-45**	**3-Spray**
Twist 0.75 + Opus 0.5	5.6	2.6	1.5	1.5
Twist 1.5 + Opus 0.5	3.1	2.6	0.7	
Amistar 0.5 + Opus 0.5	5.5	2.5	1.2	
Amistar 1.0 + Opus 0.5	6.8	1.3	2.0	

Biggleswade

In 1999, all of the single-spray treatments had higher levels of *S. tritici* on leaf 2 than the three-spray control (Table 3.3.4). Full rates were more effective than half rates regardless of fungicide used and timing, but this was particularly true for Amistar + Opus, which performed less well at half rate at both GS32 and GS37.

Table 3.3.4 Effect of fungicide strategy on disease control (Biggleswade, 1999)

Treatment (l/ha) Spray Timing	% *S. tritici* on leaf 2 at GS75			
	GS32	**GS37**	**GS39-45**	**3-Spray**
Landmark 0.5	8.5	7.8	10.0	0.7
Landmark 1.0	6.3	4.8	8.4	
Amistar 0.5 + Opus 0.5	24.1	10.4	9.9	
Amistar 1.0 + Opus 0.5	11.9	3.7	6.8	

Favourable disease conditions at Biggleswade in 2000 resulted in both *S. tritici* and brown rust occurring on leaf 2 (Table 3.3.5). None of the single spray strategies matched the three-spray for brown rust control, however the full and half-rates of Landmark and the full rate of Amistar at GS37 were equally effective against *S. tritici* on leaf 2. Single applications at GS39-45 were particularly weak against *S. tritici* in this trial.

Table 3.3.5 Effect of fungicide strategy on disease control (Biggleswade, 2000)

Treatment (l/ha) Spray Timing	% *S. tritici* / brown rust on leaf 2			
	GS32	**GS37**	**GS39-45**	**3-Spray**
Landmark 0.5	6.3 / 11.1	2.0 / 3.4	15.1 / 7.2	3.4 / 0.8
Landmark 1.0	4.3 / 13.2	0.6 / 3.4	15.1 / 15.5	
Amistar 0.5 + Opus 0.5	5.6 / 9.4	9.1 / 20.6	15.8 / 11.1	
Amistar 1.0 + Opus 0.5	7.0 / 4.6	2.8 / 3.2	9.4 / 2.9	

In 2001, only the higher dose of Twist + Opus at GS37 gave equivalent control of *S. tritici* to the three-spray control. Full dose rates were beneficial at both GS32 and GS37, but not at GS39-45. Twist + Opus gave better control of *S. tritici* on leaf 2 than Amistar + Opus, especially after GS32. The optimum single timing was therefore GS37 for Twist + Opus, but GS32 for Amistar + Opus.

Table 3.3.6 Effect of fungicide strategy on disease control (Biggleswade, 2001)

Treatment	**% *S. tritici* on leaf 2 at GS75**			
(l/ha) Spray Timing	**GS32**	**GS37**	**GS39-45**	**3-Spray**
Twist 0.75 + Opus 0.5	3.1	1.8	2.8	1.0
Twist 1.5 + Opus 0.5	1.7	1.1	3.8	
Amistar 0.5 + Opus 0.5	3.9	5.5	6.2	
Amistar 1.0 + Opus 0.5	2.2	4.0	7.8	

3.4 Effect of Single-Spray Fungicide Strategies on Grain Specific Weight (1999-2001)

Grain samples taken from the Biggleswade trials were tested for specific weight (Table 3.4.1). None of the single-spray treatments were consistently inferior to the three-spray control. However, applications at GS37 or GS39-45 generally resulted in higher values than single sprays at GS32. There was no evidence of an advantage to the full dose rate compared to the half rate treatments.

Table 3.4.1 Effect of fungicide strategy on specific weight (Biggleswade, 1999-2001).

	Specific Weight (kg/hl)						
Timing	**GS32**		**GS37**		**GS39-45**		**3-Spray Control** (GS32, 39, 59)
Fungicide Treatment	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	Amistar 0.5 + Opus 0.5	Amistar 1.0 + Opus 0.5	
1999	72.5	71.5	70.9	71.1	73.2	70.1	72.0
2000	72.3	72.2	72.5	75.1	74.0	74.8	74.7
2001	72.2	72.1	72.6	72.4	72.2	72.3	72.2
3 Year Mean	72.3	71.9	72.0	72.9	73.1	72.4	73.0

4. Discussion

Over the three-year period from 1999-2001, the only year in which significant yield penalties were recorded from almost all single-spray fungicide strategies was 2000. However, only this season would be considered to have had high disease pressure at the two locations. Whilst the results from 2000 are the best indicator of the level of risk and potential yield loss that might be attached to a single-pass fungicide strategy in a *S. tritici* (and brown rust) situation, the trials were deliberately conducted on a highly disease-susceptible variety. In practice such an approach might only be considered on varieties with a reasonable level of disease resistance.

Under low disease pressure in 2001, application timing had no impact on final grain yield. Where there was an effect in the previous two seasons, it was always GS37 or GS39-45 that produced the highest output. These later timings would have been expected to be more effective at protecting the main yield-generating leaves. The three-year mean yields appear to show a slight advantage to GS39-45 at Andover, and GS37 at Biggleswade, however this was heavily influenced by the responses from 2000.

Whilst the GS32 timing gave the lowest yields over the three years, it was however the least responsive to the use of the full fungicide rates, indicating that simply using a higher dose rate would not have compensated for application too early. There was an indication at Biggleswade that where application was later than optimum, using the full dose rate did bring yield closer to that achieved by application at the optimum timing of GS37.

At Andover all of the single spray strategies were more cost-effective than the three-spray programme in 2001, even if savings in application cost are ignored. With one slight exception, the same was true at Biggleswade. In 1999, only some of the single sprays gave a higher margin over chemical cost at Andover, but if application costs are included they were all more cost-effective than the three-spray control. At Biggleswade, most of the single sprays gave a lower margin over chemical cost, but were again more cost-effective if application costs are included. In 2000, the only single spray treatments to match the three-spray programme were those applied at GS39-45 at Andover, with all others resulting in substantial losses.

Taking the average of the six single-spray strategies that were examined in all three seasons, at Andover the average loss compared to the three-spray programme was £17/ha, but only £3/ha if application costs of £7/ha per spray pass are included. At Biggleswade, losses were slightly greater at £25/ha and £11/ha respectively. Interestingly, Biggleswade would be considered as a lower disease pressure location due to its lesser rainfall and historically lower incidence of *S. tritici*. However, failure to maintain control brown rust at this site has often resulted in substantial penalties, particularly where the end of season fungicide spray has been omitted.

Although the single-sprays did not often result in significant yield penalties compared to the three-spray programme, they almost invariably gave inferior disease control, even in 2001. For example, at Andover in 1999, the incidence of *S. tritici* on leaf 2 increased from 12% in the three-spray to 63-83% in the GS32 single-spray treatments, but the associated yield penalty was only between 1 and 6%. However, the absolute levels of disease were lowest in 2001, with almost all treatments recording less than 5% *S. tritici* on leaf 2.

At Andover in 2000, the single-spray timing that gave the best control of *S. tritici* on leaf 2 (GS39-45) was also the timing that gave the highest yields. GS32 applications gave the poorest disease control on leaf 2 in all three years at Andover, whereas at Biggleswade the GS39-45 single sprays were equally ineffective. This helps to explain why GS37 appeared to be the highest-yielding single timing at Biggleswade, whereas at Andover it was GS39-45. At Biggleswade in 2000, control of brown rust was penalised more than the control of *S. tritici* by the change from a three-spray programme to the single-spray strategies.

5. Conclusions and Implications

Based on three-year mean performance in these trials, a single-spray fungicide strategy, based on a robust mix of a strobilurin and a triazole, offers a realistic ‘minimum pass’ alternative to a three-spray programme in winter wheat. However, there are a number of important considerations:

- The level of risk attached is higher, so this should be minimised by only using the approach on varieties with good overall disease resistance.
- Single-spray strategies are unlikely to be substantially <u>more</u> profitable than a multi-spray programme, but may be much <u>less</u> profitable in high disease pressure seasons.
- A minimum pass approach is more likely to be cost-effective where each spray pass is considered to have a direct cost attached. Savings in agrochemical cost alone are less likely to justify the technique.
- For a single fungicide spray to be effective, correct application timing is vital, particularly under high disease pressure. This is most likely to be during, or just after, flag leaf emergence (GS37-45), in order to maximise protection of the top two leaves.
- Under low disease pressure the window may be wider, and earlier application (GS32-37) might be as effective.
- In the event that disease risk increases during the course of the season, flexibility to increase the dose rate of the single-spray treatment would be important.
- Where this change occurs earlier, it may be more appropriate to revert to a multi-spray programme.
- Where the threat of fungicide resistance exists, it would be unwise to allow high disease levels to establish before applying the first fungicide treatment.